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Electric & Hybrid Vehicle System
Research & Development Project

DOE/CS-54209-22
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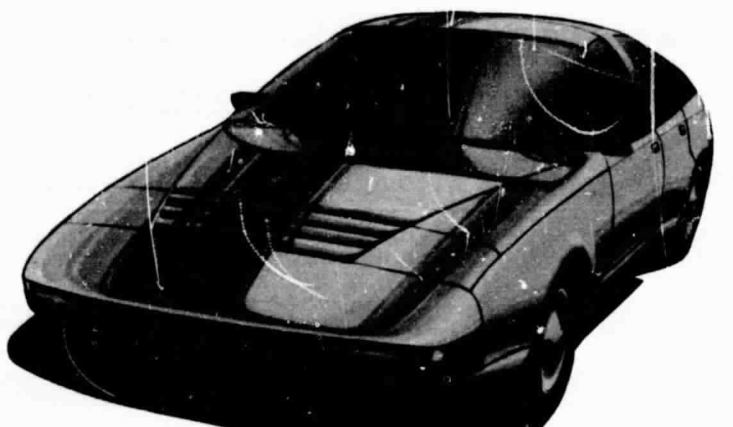
Advanced Vehicle Systems Assessment

Volume V: Appendices



March 1985

Prepared for
U.S. Department of Energy
Through an Agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
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Pasadena, California

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16. Abstract

Volume V, the Appendices, includes reports on battery design, battery cost, aluminum vehicle construction, IBM PC computer programs, and battery discharge models. Other volumes are Volume I, Executive Summary, Volume II, Subsystems Assessment, Volume III, Systems Assessment, and Volume IV, Preference and Aftermarket Analyses.

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ABSTRACT

This report, which is divided into five volumes, documents the evaluation of advanced electric and hybrid vehicles for potential development by the early 1990s. The primary objective of the assessment is to recommend subsystem research priorities based on a comparison of alternatives as part of complete vehicle systems with equivalent performance. The assessment includes evaluations of candidate technologies as well as technical and economic comparisons of vehicle systems for specified missions. The availability of nonpetroleum fuel is also addressed, and preference analyses are used to assist in the evaluation of the relative merits of competing systems.

Volume V, the Appendices, includes reports on battery design, battery cost, aluminum vehicle construction, IBM PC computer programs, and battery discharge models. Other volumes are Volume I, Executive Summary, Volume II, Subsystems Assessment, Volume III, Systems Assessment, and Volume IV, Preference and Aftermarket Analyses.

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BATTERY DISCHARGE MODELS

APPENDIX A

GUIDELINE FOR CONTRACTOR RESPONSE

GUIDELINE FOR CONTRACTOR RESPONSE

This version of the guideline addresses the concerns expressed by the review board and battery developers at the Electric Hybrid Vehicle (EHV) Systems Assessment Seminar. Battery sizes are expressed explicitly, and the questions are geared toward complete battery systems rather than specific energy or power.

Table A-1 illustrates the differences in power and energy requirements determined for vehicles simulated to date, depending on the application (using the current models). Several examples of electric vehicles and perhaps the most extreme hybrid vehicle (full-power capability in electric mode) are shown, which bound the extremes of power-to-energy ratio (P/E). The P/E ratio defines the ratio of the power available for acceleration and the energy required to meet the range requirement so that the vehicle would "run out" of power and energy at the same time, and therefore would not be overdesigned with respect to either characteristic. The variation in the specification is the result of the differences in specific energy and specific power between the batteries, which resulted in variations in vehicle weight.

Table A-1. Differences in Power and Energy Requirements

	Battery Requirements[a]			
Vehicle Type	Power, kW	Vehicle Specific Power, W/kg_{VTW}[b]	Energy, kWh	Vehicle Specific Energy, WH/kg_{VTW}
4-Pass 80-km HV (P/E = 3.3-3.8)	36-41	30	9-11	8-9
5-Pass 80-km HV (P/E = 3.3-3.8)	44-50	30	13-15	8-9
3/4 Ton 96-km Van (P/E = 2.3-2.6)	46-57	23	20-23	9-10

[a]Battery energy requirements are on the Federal Urban Driving Schedule and do not include self-discharge, thermal losses, etc. Power requirements are for 30 seconds at low state of charge (i.e., typically 10 to 15%).
[b]Vehicle Test Weight.

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Table A-1. Differences in Power and Energy Requirements (Continued)

	Battery Requirements[a]			
Vehicle Type	Power, kW	Vehicle Specific Power, W/kg_{VTW}[b]	Energy, kWh	Vehicle Specific Energy, WH/kg_{VTW}
2-Pass 128-km EV (P/E = 2.1-2.3)	20-26	25	9-12	11-12
5-Pass 160-km EV (P/E = 2.1-2.3)	37-58	30	18-26	13-14
5-Pass 240-km EV (P/E = 1.5-1.6)	44-58	30	27-36	19-20
4-Pass 400-km EV (P/E = 0.9-1.0)	32-43	30	46-56	30-32
5-Pass 400-km EV (P/E = 0.9-1.0)	40-53	30	53-56	30-32

[a]Battery energy requirements are on the Federal Urban Driving Schedule and do not include self-discharge, thermal losses, etc. Power requirements are for 30 seconds at low state of charge (i.e., typically 10 to 15%).
[b]Vehicle Test Weight.

Interpretation of the information in Table A-1 would lead to the following estimates of delivered energy and power requirements for batteries in advanced vehicles, although detailed analysis is ultimately required for each case (due to self-discharge, etc.):

(1) Commuter vehicle battery - 12 kWh, 25 kW.

(2) Hybrid vehicle battery - 15 kWh, 50 kW.

(3) General-purpose Electric Vehicle (EV) or commercial van battery - 25 kWh, 60 kW.

(4) Full-performance EV battery - 50 kWh, 50 kW.

These specifications are distinct, and the following questions are designed to determine the specific performance, cost, and volume of these batteries. The guideline has been organized into seven basic categories: performance modeling, cost projections, technical support for projections, energy balance, life considerations, other operational characteristics, and

packaging flexibility. You should make every effort to respond to all the categories and supply any appropriate data or designate where there is insufficient data to support a projection.

Several ground rules must be established in an effort to standardize the projections as much as possible. Battery projections should be made for a one-year-old battery operating in 70° F ambient air. The technology projections should be limited to batteries that could be demonstrated in prototype form in the early 1990s (i.e., 1990 to 1992) and the range of applicability should be stated (i.e., 10 to 50 kWh?).

1. PERFORMANCE MODELING

(a) Battery discharge characteristics for the present battery and projections for batteries with the previous specifications. If unable to meet the extremes, specify the limiting cases. Please respond in tabular form below with the specific energy yielded as a function of the constant discharge rate specified. Identify range of applicability and any scaling concerns.

	Specific Energy (Wh/kg) Versus Discharge Rate				
Battery Design	20 W/kg	60 W/kg	80 W/kg	100 W/kg	200 W/kg
1 - Present					
2 - Commuter					
3 - Hybrid					
4 - EV or Van					
5 - Full-Perf.					

(b) 30-second peak specific power capability versus state of charge (as defined for the standard C/3 or C/4 rates).

	30-second power capability (W/kg)			
Battery Design	80% SOC	50% SOC	30% SOC	10% SCC
1 - Present				
2 - Commuter				
3 - Hybrid				
4 - EV or Van				
5 - Full-Perf.				

2. COST PROJECTIONS

Production price to the Original Equipment Manufacturers (OEMs) in quantities of 100,000 units per year. The estimates should be per A. D.

Little guidelines and your opinion of the assumed values in the guidelines should be specified where they differ from your own. Estimates should include all thermal management or servicing systems (i.e., watering).

Battery Design	$/battery
1 - Present	
2 - Commuter	
3 - Hybrid	
4 - EV or Van	
5 - Full-Perf.	

3. TECHNICAL SUPPORT FOR PROJECTIONS

List how the performance improvements would be obtained over the present battery capabilities in the following format. Try to be as specific as possible to allow the review board to adequately assess the credibility of the projections (i.e., current collectors, active material, separators, case, auxiliaries, etc.). Specify trends if nothing else, and supplement the table with explanation, if necessary.

Component	Present Status	Design Change	Performance Change	Cost Change	Comments

4. ENERGY BALANCE

It is necessary to quantify sources of energy use other than that reflected in the performance modeling. This includes any notable start-up or shut-down energy, self-discharge and shunt currents, parasitics, thermal effects (i.e., heat transfer that must be replaced by electricity), charge efficiency, etc. This is necessary to reflect in-use efficiency over 24-hour driving schedules as simulated in the AV Assessment. A simplified 24-hour driving pattern is used here to allow your estimation of energy use (see Table A-1). The driving portion (designated driving cycle 3) was proposed by JPL to the EHV Battery Task Force as a greatly simplified version of the Federal Urban Driving Schedule to be used for life-cycle testing. This cycle retains the peak power as well as other critical parameters of the original cycle. The distance of 46 km (29 mi) is approximately the average daily trip length of a 16,000 km/yr (10,000 mi/yr) vehicle. You are asked to estimate the energy use by segment of the cycle in the table supplied on the following page. The details of the cycle are included at the end of the guideline to support detailed analyses, if necessary. The values in the table should be specified as power (Watts) assumed continuous over the segment or total energy (Watt-hours) for the segment. Please comment if there are special circumstances to consider or any other concern for the way the estimates are to be used.

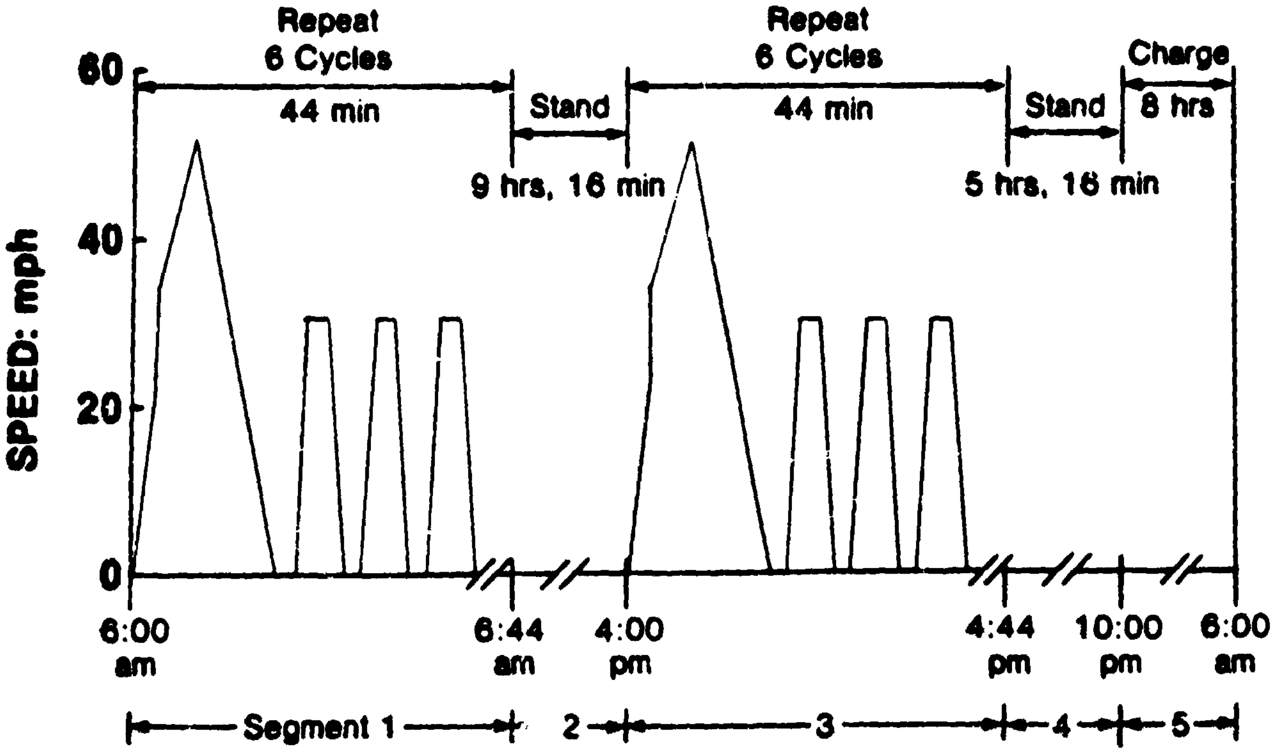

Figure A-1. Simplified 24-h Driving Pattern

ESTIMATES OF IN-USE ENERGY CONSUMPTION

Parameters	Segments 1	2	3	4	5
Start-up and shut-down					
Self-discharge					
Shunt current					
Parasitics					
Thermal loss[a]					
Charge Eff.[b]					

[a]Only that which requires replacement by electricity (specify electrical-to- thermal efficiency).
[b]Specify charger efficiency as well if unique to battery.

5. LIFE CONSIDERATIONS

(a) Present status of cycle life, including statistical background and life-limiting mechanisms.

	Cycle Life	Depth-of-Discharge	Life-limiting Mechanisms	Statistical Background
Cells				
Modules				
Batteries				

(b) Projected cycle life, including approach to solving failure modes and effects on cost. Specify any differences between high-power and high-energy designs.

(c) Life effects on specific power and energy, efficiency, thermal characteristics (i.e., linear degradation with cycle life?)

(d) Estimate of reliability of smallest replaceable block of cells in a battery, failure modes, mean-time-to-failure, etc.

6. OTHER OPERATIONAL CHARACTERISTICS

(a) Special Charge Requirements

What happens if the cells are over-charged or over-discharged?

Is individual cell balancing required? If so, how often?

Is periodic complete discharge required? It so, how often?

Is equalizing necessary? If so, how often?

(b) Maintenance Requirements

What regular maintenance is required? How often?

What potential exists for battery refurbishment rather than replacement? How does this compare in cost with replacement?

7. PACKAGING FLEXIBILITY

(a) Volumetric considerations for various designs

	liters
1 - Present	
2 - Commuter	
3 - Hybrid	
4 - EV or Van	
5 - Full-Perf.	

(b) Size limitations

What are the minimum possible measurements of the battery cells or modules (i.e., height, width, length), and what are the primary considerations in changing from the present configuration?

(c) Any special consideration for relative placement of subsystems in a vehicle (i.e., necessity to place fluid reservoir near cell stack)?

(d) Scale effects in the 10- to 50-kWh range, if applicable.

CYCLE 3

Cycle Segment No.	Cycle Segment Time, s	Type[a]	Energy consumed, W-s/kg	Average Power, W/kg
1	0 - 26	A	298	12
	26 - 30	A	358	89
	30 - 74	A	1428	33
	74 - 76	A	94	47
	76 - 171	D	-265	-3
2	171 - 196	S	0	0
	196 - 211	A	497	33
	211 - 236	C	175	7
	236 - 251	D	-155	-10
3	251 - 276	S	0	0
	276 - 291	A	497	33
	291 - 316	C	175	7
	316 - 331	D	-155	-10
4	331 - 356	S	0	0
	356 - 371	A	497	33
	371 - 396	C	175	7
	396 - 411	D	-155	-10
	411 - 436	S	0	0

[a]A - acceleration.

D - deceleration.

S - stand.

C - cruise.

APPENDIX B

NICKEL-IRON BATTERY DESIGN ANALYSIS

NICKEL-IRON BATTERY DESIGN ANALYSIS
IN SUPPORT OF THE
ELECTRIC AND ELECTRIC HYBRID VEHICLE
PROJECT

BY:

EAGLE-PICHER INDUSTRIES, INC.
JOPLIN, MISSOURI

FOR:

JET PROPULSION LABORATORY
CONTRACT 956781
TASK RE-152/170

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1.0 SUMMARY

The estimates presented in this report are based on the established performance of the nickel-iron battery from 1980 through 1983. The projections for the advanced batteries, 1986, are based on the extrapolation of existing data as designs are modified to favor specific energy or power. The narrow difference between the present and the "advanced" battery indicates the maturity of this technology compared to what is ultimately possible in the nickel-iron system. additionally the relatively modest differnces between "power" and "energy" designs indicates that standardization to eliminate manufacturing differences and reduce costs slightly would be advantageous for this near term battery. The cost estimate for the battery is based on the analysis completed for ANL in May 1983. Because the main cost driver in this system is the nickel metal, the advanced batteries have less metallic nickel in the positive electrodes. The estimate is based on 85% porous plaque. The higher cost reflected in the EHV batteries compensates for the extra nickel to improve the power capability of the battery.

This analysis indicates that the nickel-iron battery will yield adequate performance for the Commuter, Hybrid and EV-Van type vehicles. In the full performance 5 passenger 400 KM EV the present battery would approach 50% mass fraction of the vehicle. The advanced battery would still be 45% of the total weight. The nickel-iron unit seems appropriate for the near term in all but the full performance applications.

TABLE 1-1

SUMMARY OF PRESENT BATTERY CHARACTERISTICS

MISSION	ENERGY	POWER	SP. ENER.	SP. PK. PWR.[x]	COST[xx]	VOLUME	WT.
	KWH	KW	WH/KG	W/Kg	$Batt.	(L)	KG
Commuter	12	25	48	> 80	2100	130	250
Hybrid	15	50	45	>120	2760	175	333
EV or Van	25	60	48	> 80	4370	260	520
Full Perf.	50	50	48	> 80	8740	520	1042

x 20% SOC

xx For Production Quan 10,000 batt/yr.

MFG - Costs

TABLE 1-2

SUMMARY OF ADVANCED BATTERY CHARACTERISTICS

MISSION	ENERGY	POWER	SP. ENR.	SP.PK PWR [x]	COST[xx]	VOLUME	WT.
	KWH	KW	WH/KG	W/KG	$BATT	(L)	KG
Commuter	12	25	56	> 100	1400	110	214
Hybrid	15	50	50	> 140	1830	155	300
EV or Van	25	60	56	> 100	2900	223	446
Full Perf.	50	50	56	> 100	5800	446	893

x @ 20% SOC

xx For Production Quan 10000 Bat/yr.

including 15% factor to approximate OEM price.

2.0 INTRODUCTION

The Eagle-Picher Nickel-Iron Battery is being developed under DOE sponsorship especially for electric and electric hybrid vehicles. The approach has been to strive for the ultimate performance from the battery while eliminating all superfluous weight. The result is a battery consisting of sintered electrodes which are light weight and of low resistance while retaining the structural integrity to survive 100% DOD cycling for over 1000 cycles. The program has progressed to the point where the achievement of its goals is imminent.

The suggested cell discharge reactions for this battery are:

$$Fe + 2OH^- \rightarrow Fe\,(OH)_2 + 2e \quad \text{(anode)}$$

$$2\,Ni\,OOH + 2\,H_2O + 2e \rightarrow 2\,Ni\,(OH)_2 + 2\,OH^- \quad \text{(cathode)}$$

$$2\,Ni\,OOH + Fe + 2\,H_2O \rightleftharpoons 2\,Ni\,(OH)_2 + Fe\,(OH)_2 \quad \text{(combined)}$$

This battery system has many advantages when compared to other units. The battery has demonstrated:

A doubling of vehicle range with the attending improved utility and decreased maintenance.

It requires no unique auxiliary equipment or periodic equalization.

It has excellent life expectancy which yields increased vehicle reliability and lowers life cycle cost.

The nickel in the battery is not consumed and is fully recoverable from expended batteries.

The present status of the Nickel-Iron Battery Development program indicates that the traditional long life expectancy of the system has not been compromised. Cells have demonstrated life cycle capability in excess of 2000, 100% DOD cycles. Modules and full size batteries have

been tested to in excess of 1000 cycles with tests continuing. One battery has been in practical service for four (4) years without degradation of performance.

3.0 BATTERY DATA

The objective of this report is to help estimate nickel-iron batteries for electric vehicles. This section presents the data upon which all the performance, size, weight and cost estimates are based. Included with the data generated by EPI is published data from JPL publication 82-91 and NBTL reports.

3.1 Specific Energy

The projected specific energy of the nickel-iron battery is 56 WH/Kg. This is the goal of the development program sponsored by DOE. Table 3-1 shows the design highlights of the present battery with alternate proposed designs to achieve the specific energy goals. A detailed comparison of the weight distribution in these designs follows in Figure 3-1, a scale weight representation of each component. The advanced battery designs save weight by reducing the electrolyte and the iron content of the cells with minor reductions in nickel grid, case material and separator weight. The accomplishment of either design, "A" or "B", requires only that the positive electrode achieve its desired performance. The status is that electrodes up to 4.0 mm in thickness have been developed. The one remaining problem is to improve their strength to be comparable with the 2.0 mm electrodes which have demonstrated excellent life characteristics.

3.2 Performance

The self explanatory data of Figures 3-2 through 3-8 outlines the general characteristics of the nickel-iron battery from constant current

TABLE 3-1

PRESENT STATUS	ADVANCED BATTERY MORE HIGHLY WORKED IRON PLATES WITH COINING AND SUPHIDE ADDED "A"	"B"
12 Pos. 2.0 MM	8 Pos. @ 3.0 MM	6 Pos. @ 4.0 MM
80% POROUS	85% POROUS	80% POROUS
85% UTILIZATION	85% UTILIZATION	85% UTILIZATION
13 NEG. @ 1.2 MM	7 NEG 1.5 MM	5 NEG @ 2.0 MM
	2 NEG 0.8 MM	2 NEG @ 1.0 MM
WORKED @ 0.65 AH/CC	WORKED @ 0.8 AH/CC	WORKED @ 0.8 AH/CC
24 SEPARATOR @ 0.85 MM	16 SEPARATOR @ 0.7 MM	12 SEPARATOR @ 0.7 MM
295 AH	295 AH	295 AH
1.23 V	1.21 V	1.21 V
7.0 KG	5.5 KG	5.6 KG
51.8 WH/KG	64.9 WH/KG	63.7 WH/KG

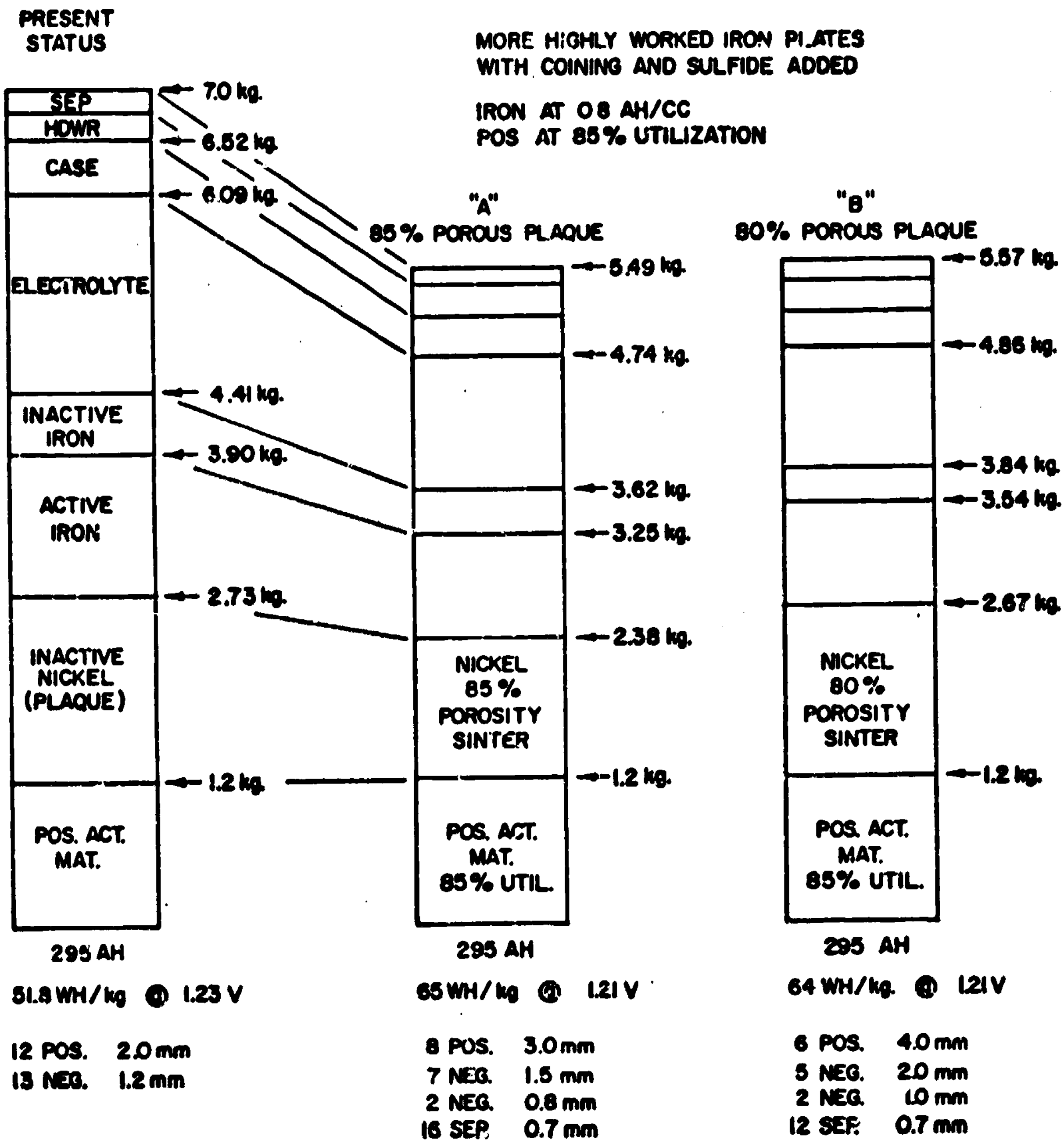
PRESENT STATUS
MORE HIGHLY WORKED IRON PLATES WITH COINING AND SULFIDE ADDED
IRON AT 0.8 AH/CC
POS AT 85% UTILIZATION
"A" 85% POROUS PLAQUE
"B" 80% POROUS PLAQUE
SEP
HDWR
CASE
ELECTROLYTE
INACTIVE IRON
ACTIVE IRON
INACTIVE NICKEL (PLAQUE)
POS. ACT. MAT.
7.0 kg.
6.52 kg.
6.09 kg.
4.41 kg.
3.90 kg.
2.73 kg.
1.2 kg.
5.49 kg.
4.74 kg.
3.62 kg.
3.25 kg.
2.38 kg.
NICKEL 85% POROSITY SINTER
1.2 kg.
POS. ACT. MAT. 85% UTIL.
5.57 kg.
4.86 kg.
3.84 kg.
3.54 kg.
2.67 kg.
NICKEL 80% POROSITY SINTER
1.2 kg.
POS. ACT. MAT. 85% UTIL.
295 AH
51.8 WH/kg @ 1.23 V
12 POS. 2.0 mm
13 NEG. 1.2 mm
295 AH
65 WH/kg @ 1.21 V
8 POS. 3.0 mm
7 NEG. 1.5 mm
2 NEG. 0.8 mm
16 SEP. 0.7 mm
295 AH
64 WH/kg. @ 1.21 V
6 POS. 4.0 mm
5 NEG. 2.0 mm
2 NEG. 1.0 mm
12 SEP. 0.7 mm

FIGURE 3-1

FIGURE 3-2

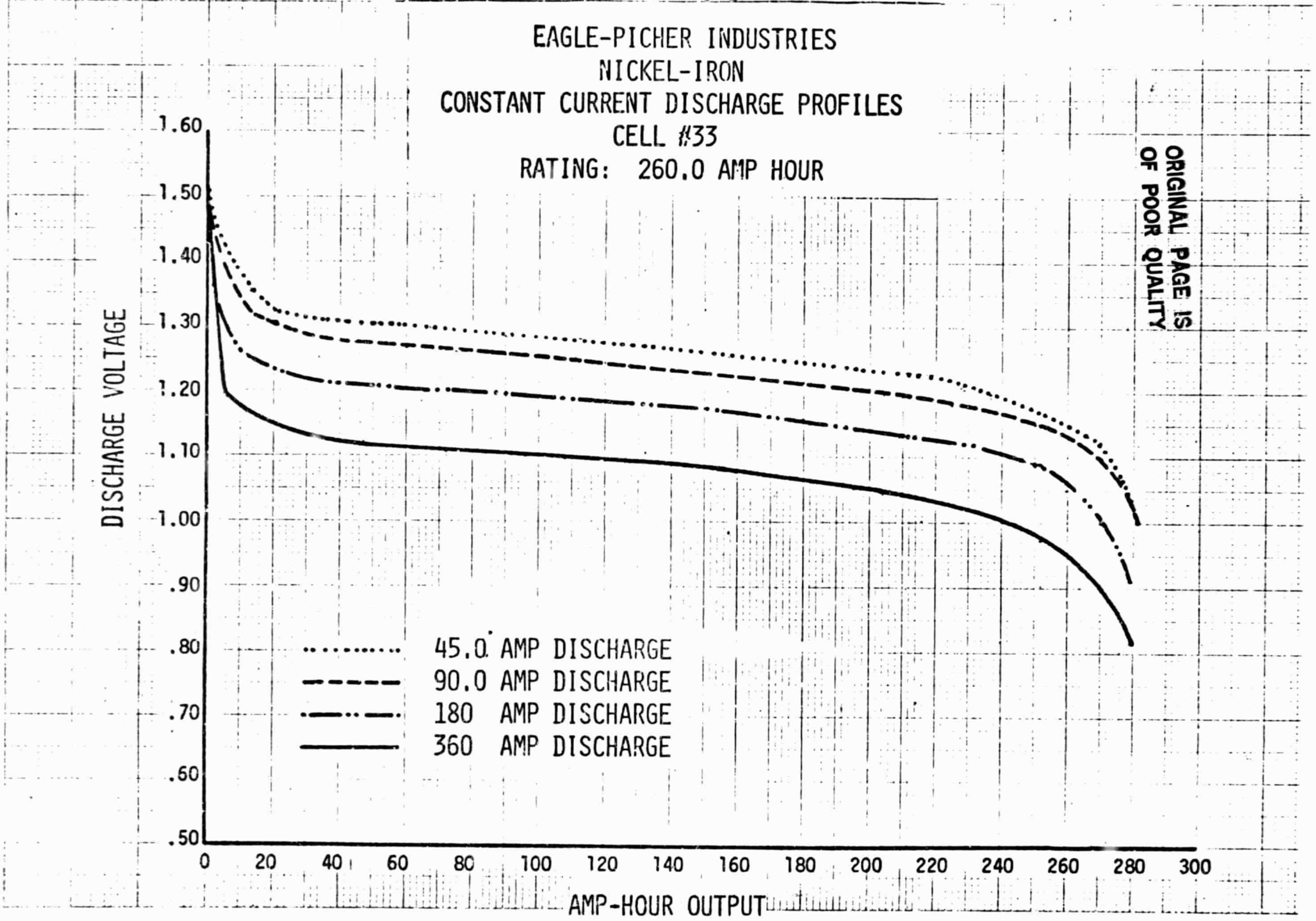
EAGLE-PICHER INDUSTRIES
NICKEL-IRON
CONSTANT CURRENT DISCHARGE PROFILES
CELL #33
RATING: 260.0 AMP HOUR
DISCHARGE VOLTAGE
1.60
1.50
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
AMP-HOUR OUTPUT
45.0 AMP DISCHARGE
90.0 AMP DISCHARGE
180 AMP DISCHARGE
360 AMP DISCHARGE

FIGURE 3-3

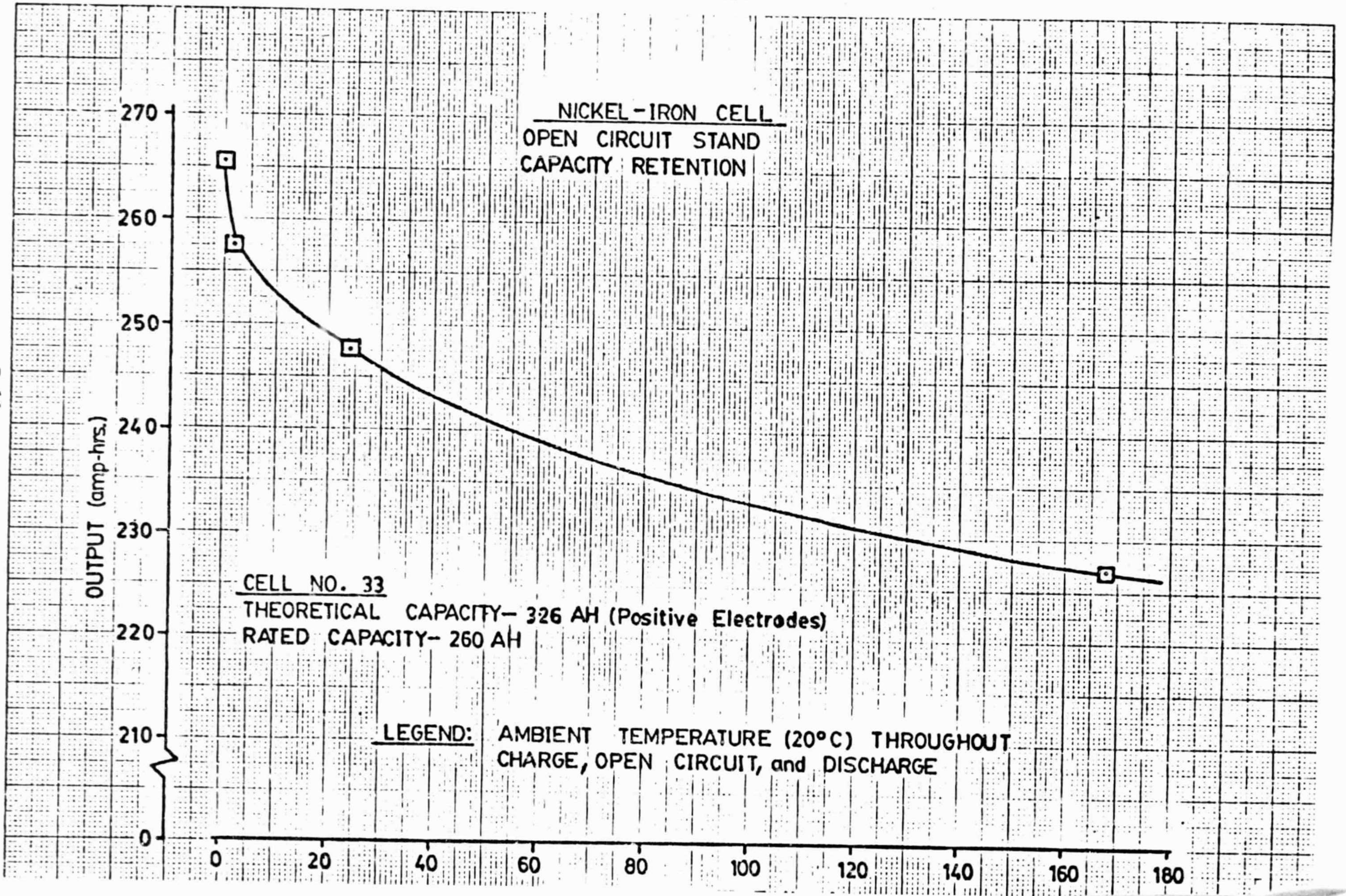

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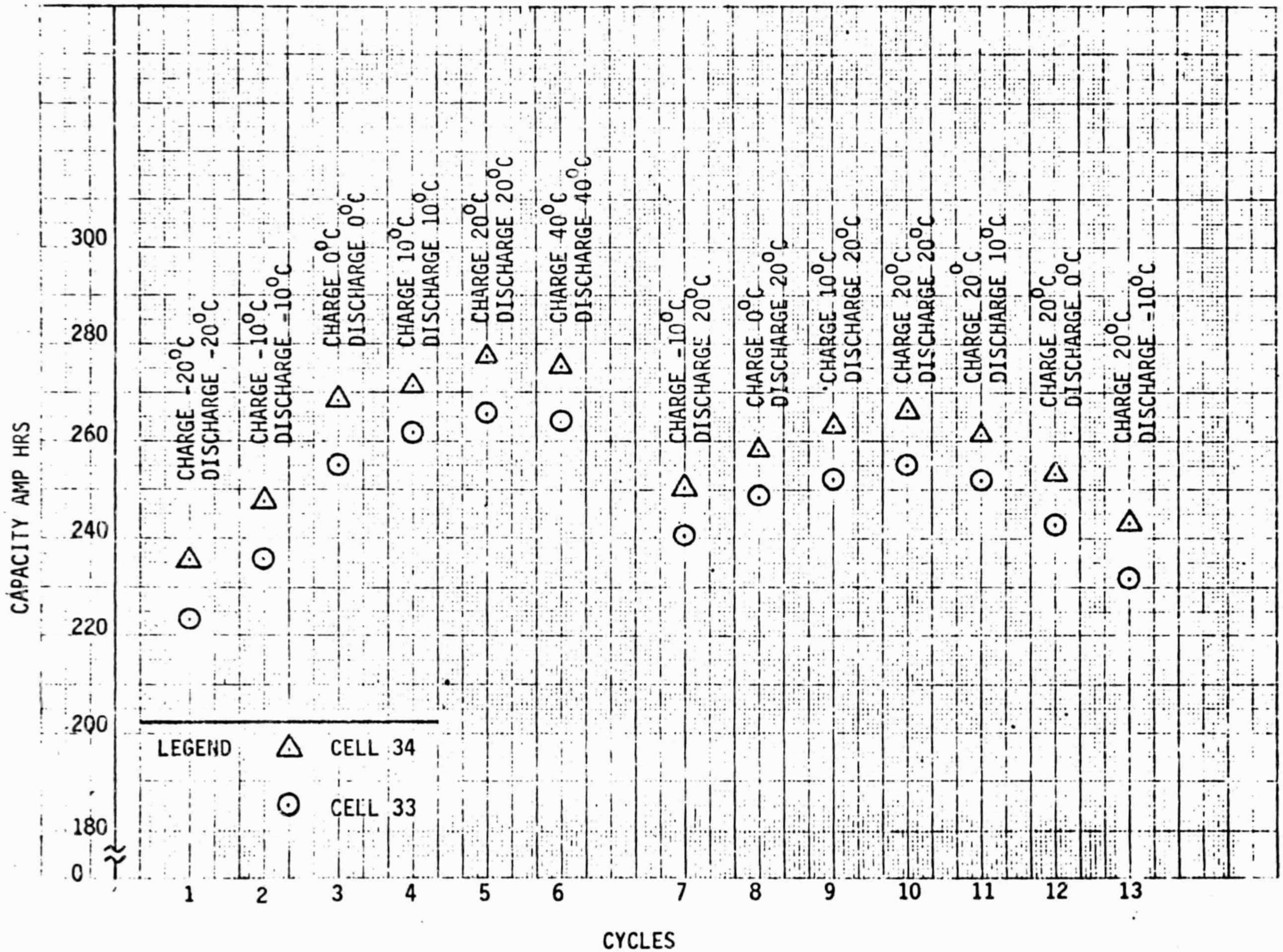
FIGURE 3-4
NICKEL-IRON VNF-270 CELL
CAPACITY VS AMBIENT TEMP.



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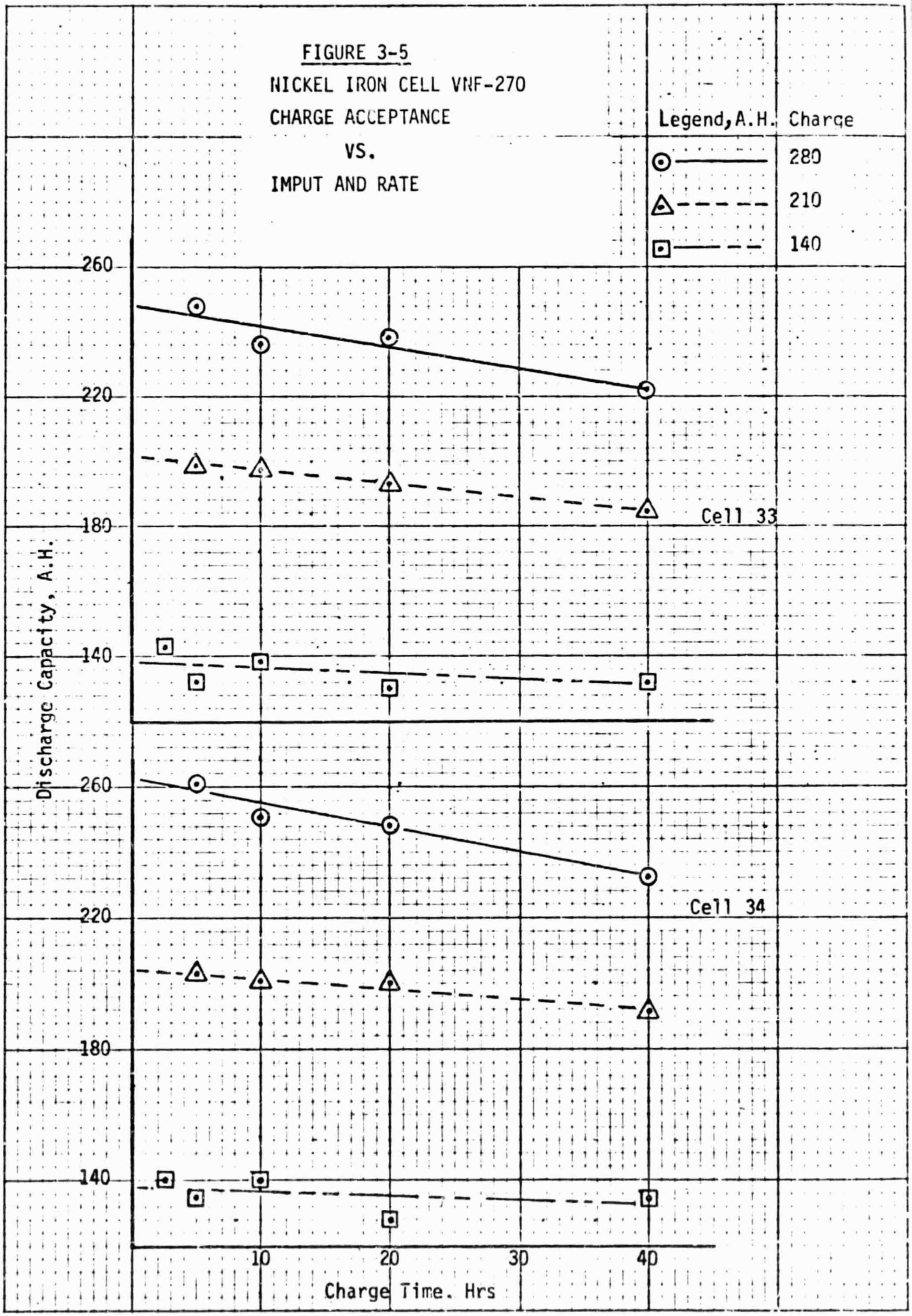

FIGURE 3-5
NICKEL IRON CELL VNF-270
CHARGE ACCEPTANCE
VS.
IMPUT AND RATE
Legend, A.H. Charge
280
210
140
Cell 33
Cell 34
Discharge Capacity, A.H.
260
220
180
140
10
20
30
40
Charge Time. Hrs

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FIGURE 3-6.
RECHARGE CHAR. VNF-270

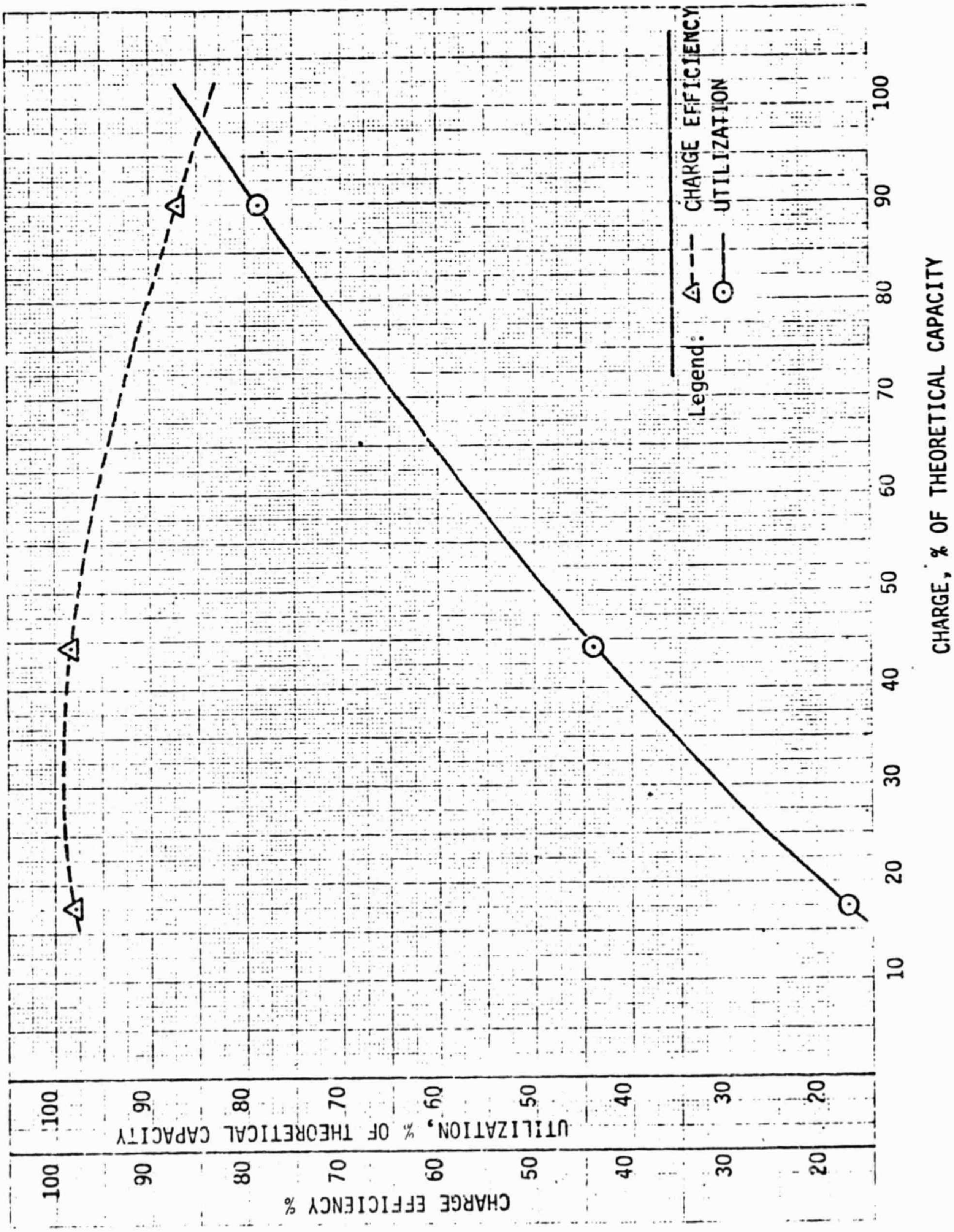


FIGURE 3-7

RECHARGE CHAR. VNF-270

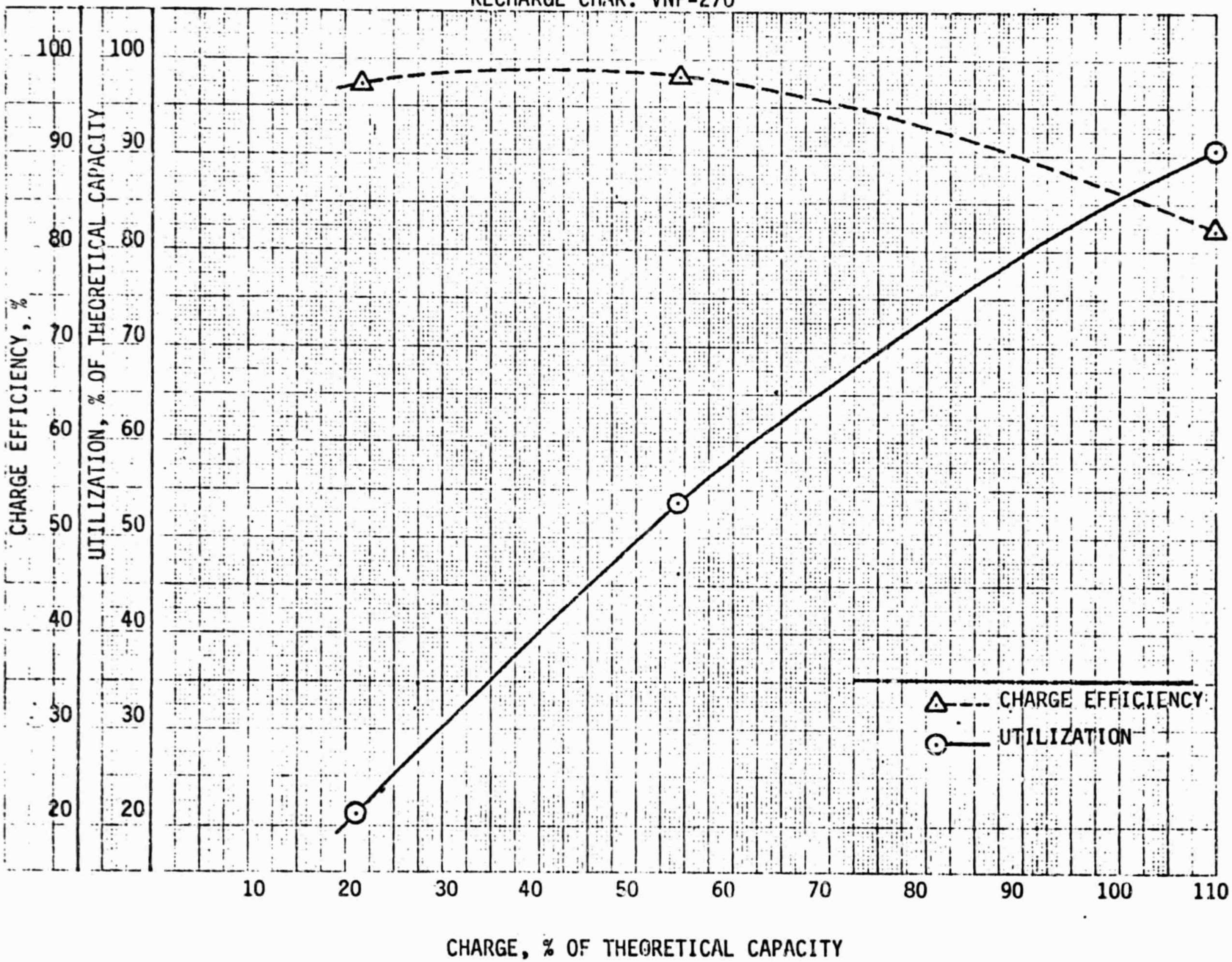
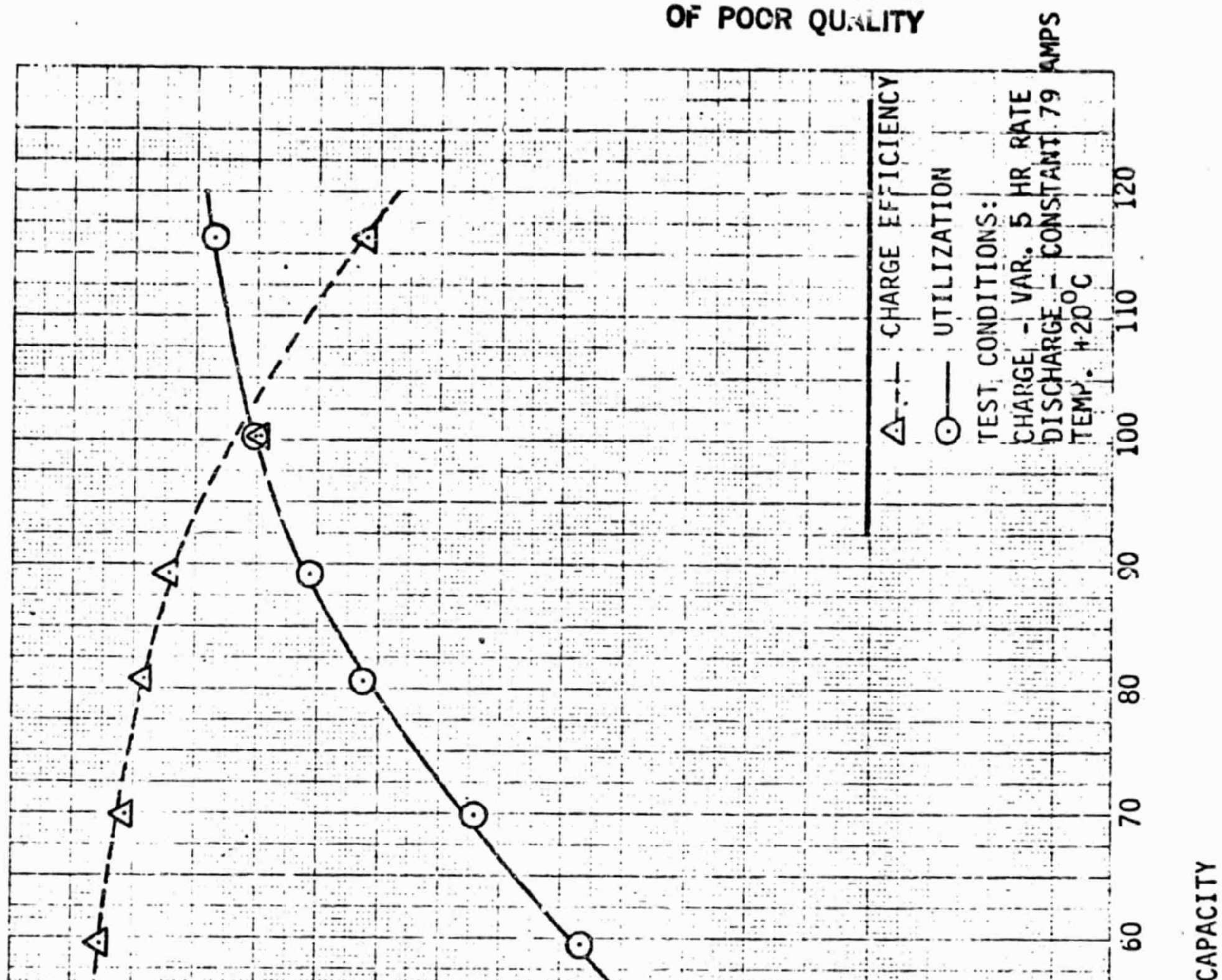


FIGURE 3-8
RECHARGE CHAR. VNF-270



discharge to charge efficiency.

3.2.1 Specific Energy vs Rate, KWH vs KW

This type presentation of the data on the VNF-270 can be derived from Figure 3-2 using the 140 AH voltage as average for the discharge, and 7.0 Kg for the weight of the cell. Each curve represents a nearly constant wattage discharge. The decrease in energy density is in proportion to the voltage decrease.

The graph of Figure 3-9 from JPL publication 82-91 shows the EPI battery energy density near 40 WH/Kg from 10 to 20 watts/Kg discharge. With an electrolyte change that battery is now operating in the region indicated near 50 WH/Kg.

The graph of Figure 3-10 shows the Ragone plot derived by the NBTL at ANL. The similarity of these curves confirms the relatively flat output vs rate characteristic of the nickel-iron battery.

3.2.2 Peak Specific Power W/Kg

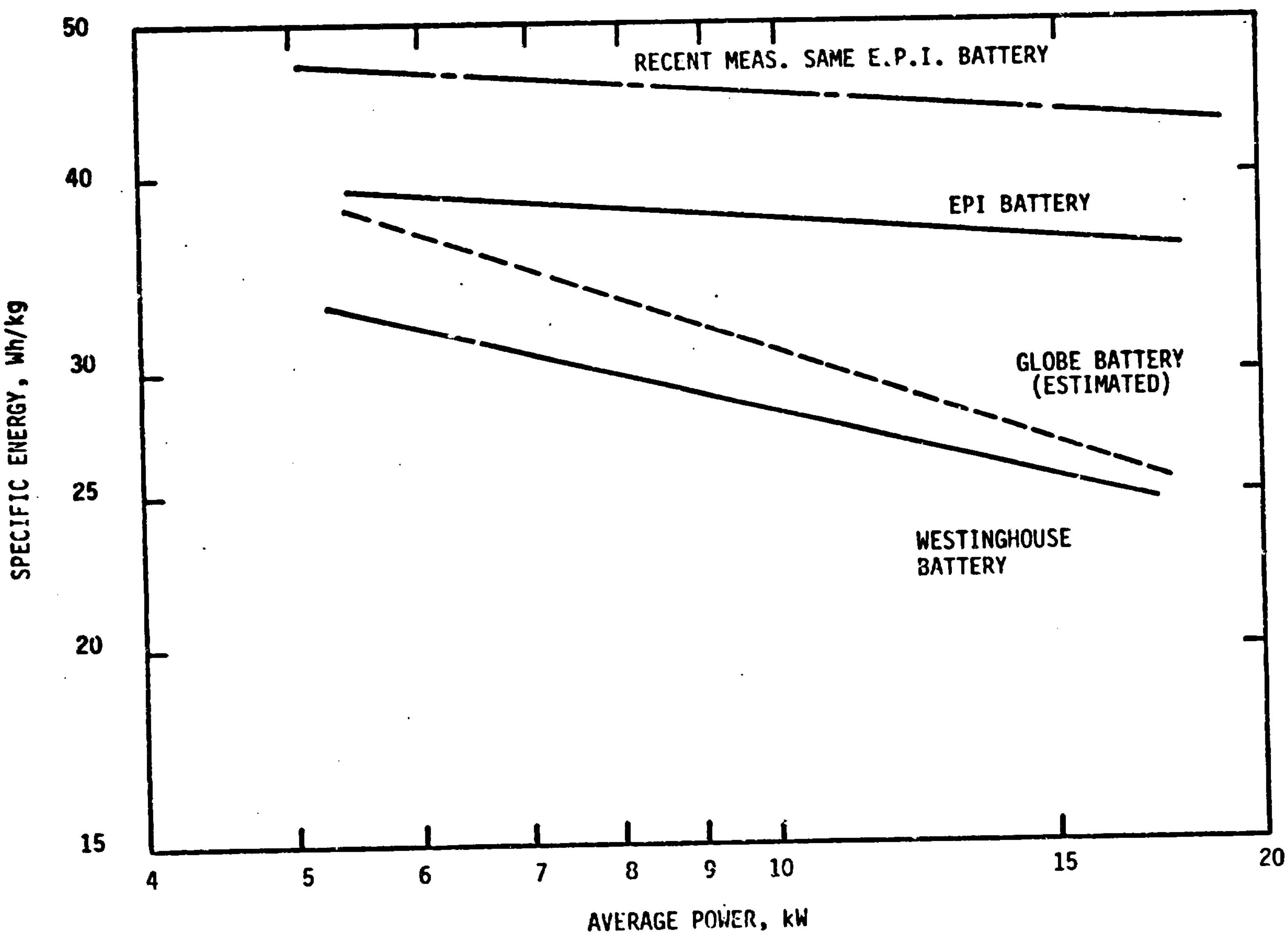
The original data for this characteristic was published by NBTL in the DOE Electric and Hybrid Vehicle Program Quarterly Report No. 11. That data is reproduced here as Figure 3-11. Figures 3-12 and 3-13 are provided to support the projections for the advanced designs. Figure 3-12 shows the immediate improvement in power available from reduced height electrodes. All the advanced batteries are based on electrodes about 130 mm high. Figure 3-13 shows that additional gains may be realized by improving the conductivity of the electrodes. Investigations to determine the optimum design continue.

3.3 Cost Projections

This information regarding the cost projection for nickel-iron

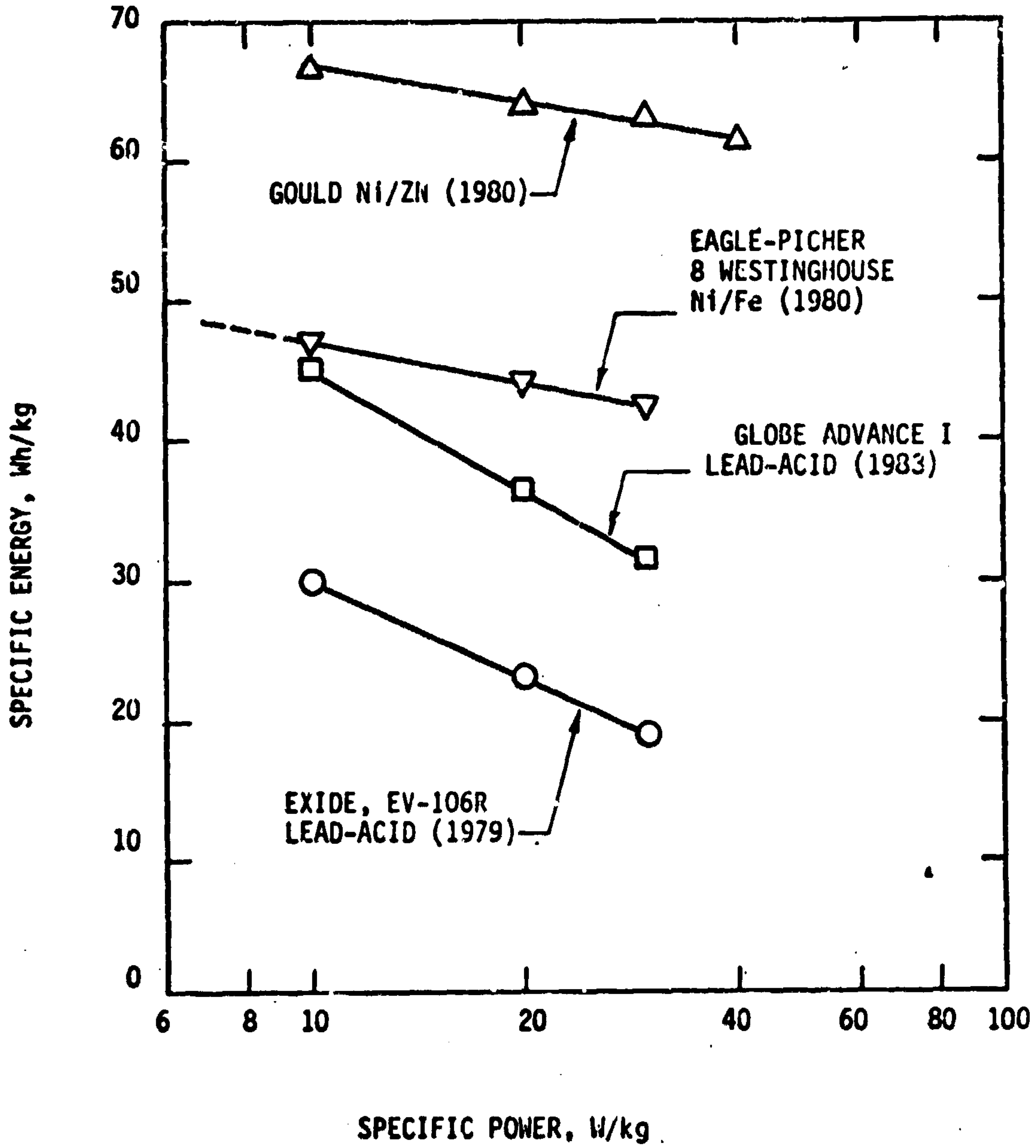
FIGURE 3-9

SPECIFIC ENERGY VS RATE



Capacity of the EPI, Globe, and Westinghouse Batteries
Immediately After Charge Termination

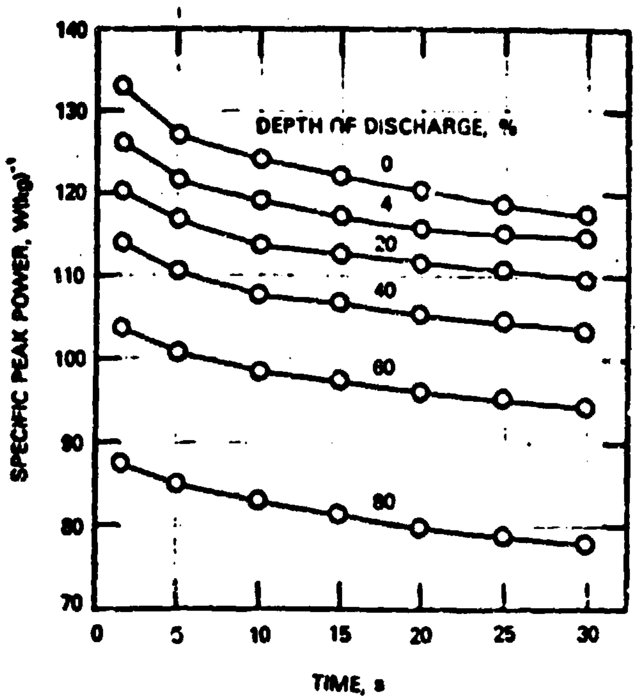
FIGURE 3-10



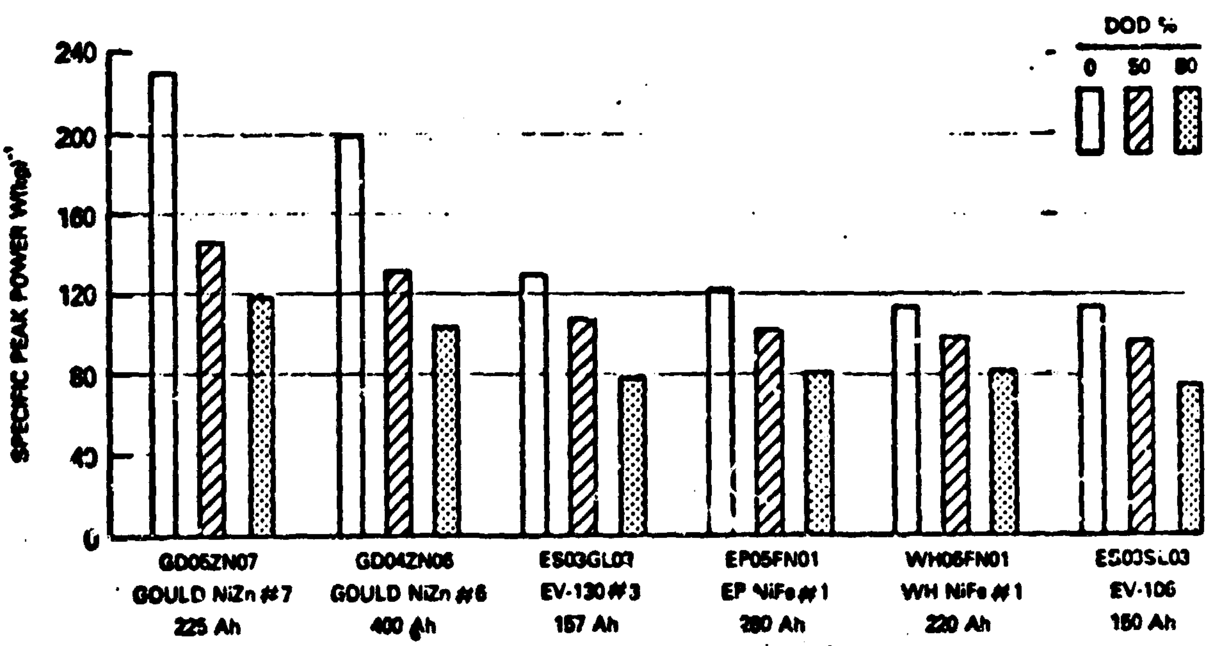
An NBTL Derived Ragone Plot Showing Specific Energy as a Function of Specific Power for Several Types of Aqueous Mobile Batteries.

ANL PEAK POWER DATA

FIGURE 3-11



Six sustained peak power versus time plots for each of six depths of discharge of an Eagle Picher 5-cell, 280 Ah, nickel/iron battery.



Specific peak power sustained for 30 second duration corresponding to three depths of discharge (DOD) for six batteries tested at the NBTL.

FIGURE 3-12

POSITIVE PLATE SHAPE
INFLUENCE ON POWER CAPABILITY

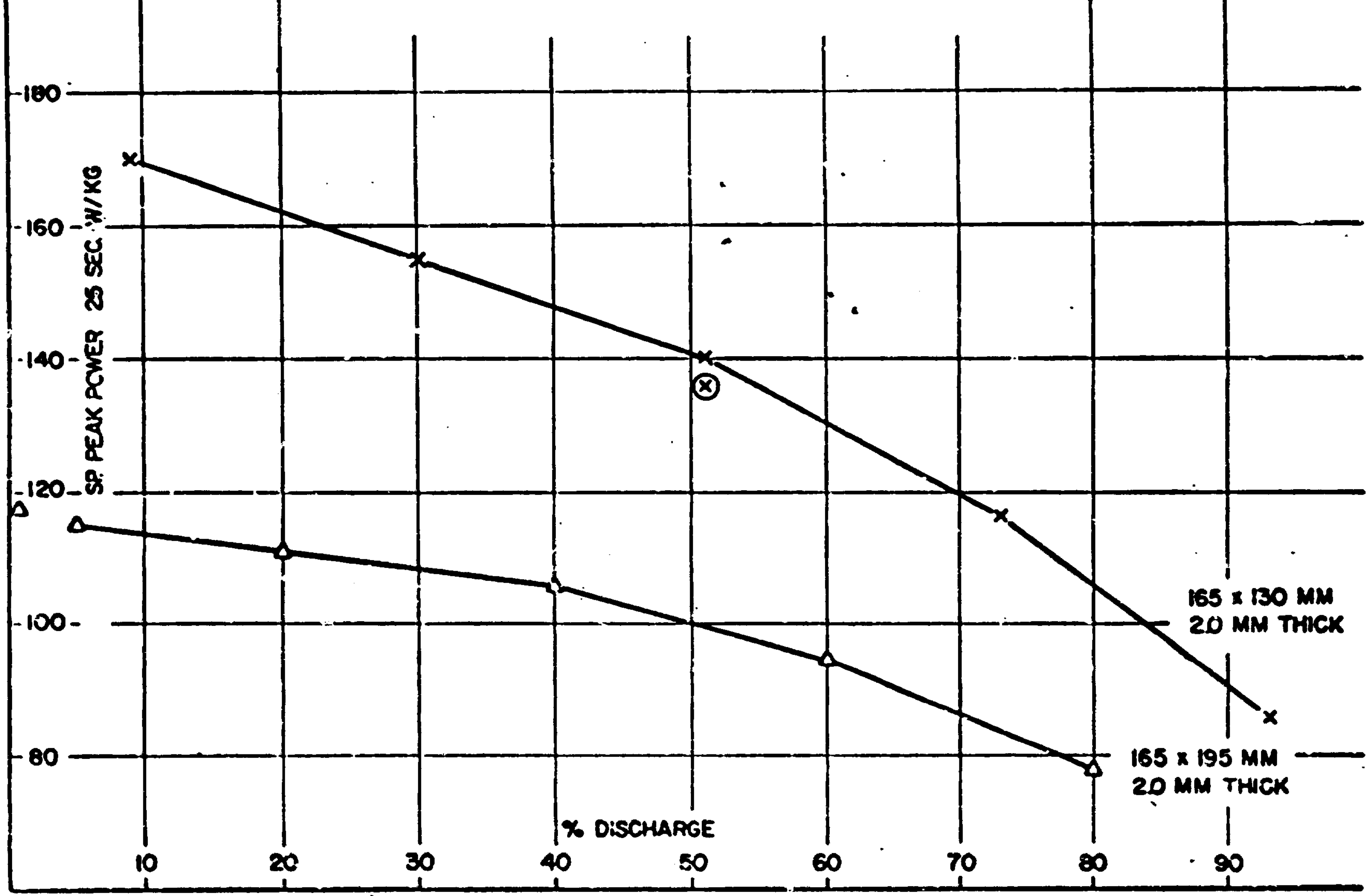
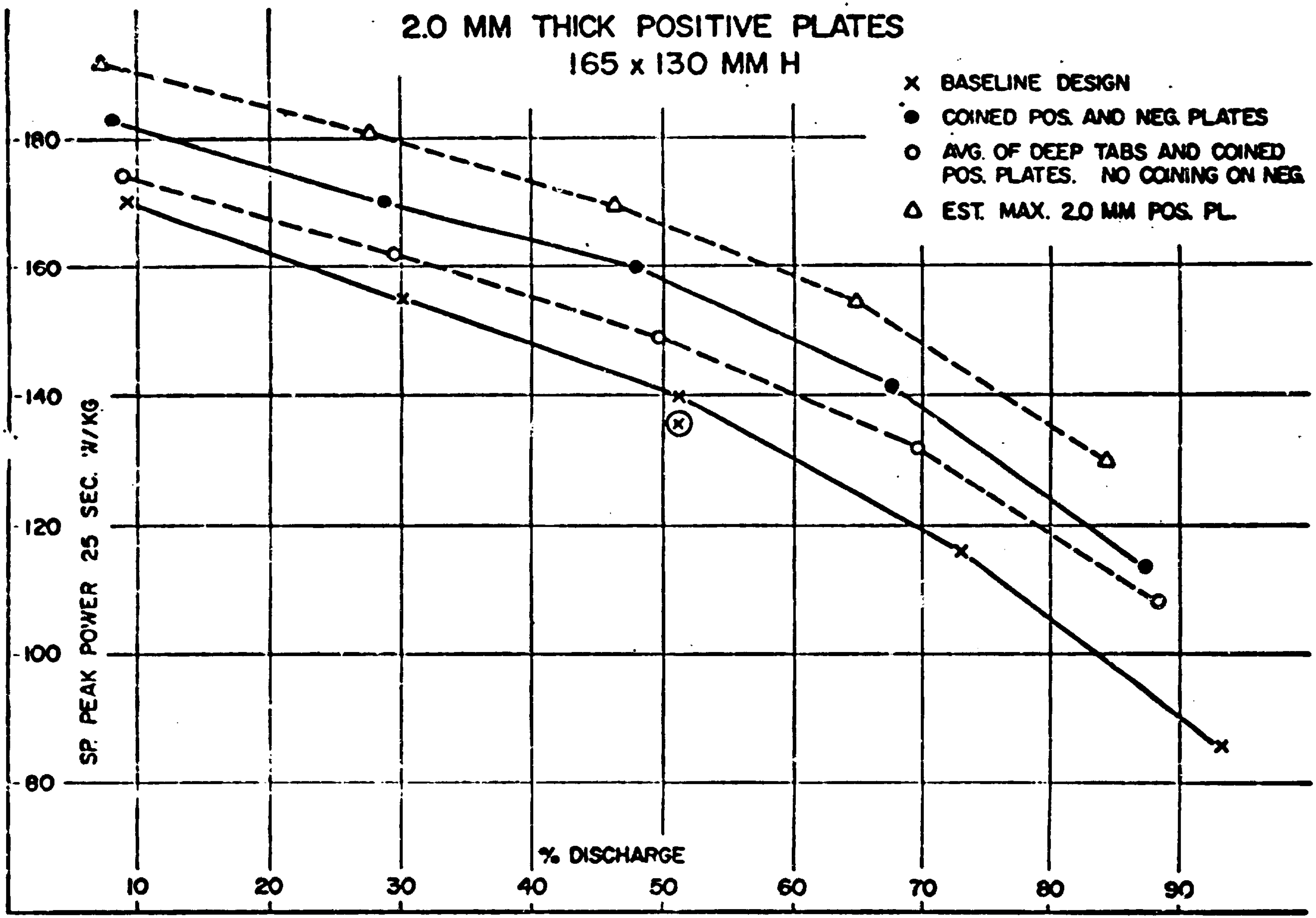


FIGURE 3-13

SP. PEAK POWER VNF 80 x 9 MODULE
2.0 MM THICK POSITIVE PLATES
165 x 130 MM H



batteries has been abstracted from an analysis performed for ANL. This information has been supplied in detailed reports to both ANL and JPL supporting the contention that battery manufacturing costs in the region of $100/KWH are reasonable.

Assumptions

1. The high energy design (using 85% porosity nickel plaque) is successful.
2. Impregnation and other plate processes under development would be utilized.
3. Battery production level at 10,000 units, 25 KWH each, per year.
4. Quotations were received late 1982 and not upgraded by cost indexing.
5. Iron electrodes would be manufactured in U.S.A.

Table 3-2 cost analysis results in 1982 dollars follows:

4.0 RESULTS AND DISCUSSION

4.1 Performance Modeling

The nickel-iron battery has not been designed for continuous discharge rates higher than 60 W/Kg. However, since it is a moderately low specific energy battery it does deliver sufficient wattage for all the vehicles. Only the watts per kilogram appear low because of the batteries weight. Table 4-1 gives the results of the calculations on the present battery 1980-1983. Table 4-2 shows the estimates for the advanced battery, 1986.

TABLE 3-2

COST ANALYSIS RESULTS

MATERIAL	$/KWH	TOTAL DOLLARS
CELL	67.02	1742.30
MODULE/BATTERY	8.76	227.68
PROCESS	7.15	185.97
LABOR		
ELECTRODE PROCESSING	12.00	312.00
POSITIVE (8.26)		
NEGATIVE (3.74)		
MODULE/BATTERY ASSEMBLY	3.74	97.20
MATERIAL HANDLING	2.67	69.60
TOTAL	$101.34	$2634.75

TABLE 4-1

PRESENT BATTERY PERFORMANCE

SPECIFIC ENERGY, WH/KG, VS. DISCHARGE RATE

BATTERY DESIGN	20 W/KG	60 W/KG	80 W/KG	100 W/KG
Commuter	48	36	30	24
Hybrid	45	39	36	33
EV or Van	48	36	30	24
Full Performance	48	36	30	24

Note that 100 W/Kg is close to the peak specific power exhibited by this battery. The hybrid battery was designed as the VNF 80x9 battery to favor power discharge. It can sustain higher discharge rates. However, the small differences in energy density to 60 W/KG discharge show that individual designs for each of the vehicle types are unnecessary.

TABLE 4-2

ADVANCED BATTERY PERFORMANCE, 1986
SPECIFIC ENERGY, WH/KG VS. DISCHARGE RATE

BATTERY DESIGN	20 W/KG	60 W/KG	80 W/KG	100 W/KG
Commuter	56	46	39	31
Hybrid	50	44	41	37
EV or Van	56	46	39	31
Full Performance	56	46	39	31

Again 100 Watts/Kg is close to the peak specific power for these batteries.

The 30 second peak specific power capability of the present battery has been measured and the data published by the NBTL. In Table 4-3 the Hybrid battery is based on the VNF 80 x 9 design which yields significantly higher peak power.

TABLE 4-3

PRESENT BATTERY PERFORMANCE 1980-1983
30 SECOND POWER CAPABILITY (W/KG)

BATTERY DESIGN	80% SOC	50% SOC	30% SOC	15% SOC
Commuter	110	100	85	70
Hybrid	170	155	135	115
EV or Van	110	100	85	70
Full Perf.	110	100	85	70

Note that the batteries, of the EV or Commuter type have demonstrated sufficient power and energy to operate the SCT and the ETV-1 and -2 vehicles for over 70 miles of the J227 "C" cycles or 55 mph driving for 100 miles.

TABLE 4-4

ADVANCED BATTERY PERFORMANCE, 1986
30 SECOND POWER CAPABILITY W/KG

BATTERY DESIGN	80% SOC	50% SOC	30% SOC	15% SOC
Commuter	160	140	120	100
Hybrid	190	170	150	130
Ev or Van	160	140	120	100
Full Perf.	160	140	120	100

4.2 Cost Projections

These cost projections are based on the data provided in section 3.3. A factor of 15% was added to the manufacturing cost data to approximate on OEM price for the batteries. The battery size in KWH delivered for 100% DOD is indicated for each type.

TABLE 4-5

BATTERY COST PROJECTIONS

BATTERY DESIGNER	SIZE KWH	PRESENT '80-'83 $	ADVANCED $
Commuter	12	2100	1400
Hybrid	15	2760	1830
Ev or Van	25	4370	2900
Full Perf.	50	8740	5800

4.3 Technical Support for Projections

The technical support for the projections presented in this report are tabulated in Table 4-6. The statements are based on the detailed data presented in Section 3.

TABLE 4-6

SUPPORT FOR PROJECTIONS

COMPONENT	PRESENT STATUS	DESIGN CHANGE	PERFORMANCE CHANGE	COST CHANGE	COMMENTS
Cell Case	Moulded ABS Plastic	Polypropylene Plastic	Smaller case Lighter Weight Higher Strength	Slight Reduction	Heat sealing tooling required high prod. rate for cost justification.
Pos. Electrode Hi Energy	2.0 mm thick 165 x 195 mm 80% porous	4.0 mm 165 x 137 mm 85% porous	Equal Performance per unit volume power & energy	Up to 25% savings in Ni Powder	Performance is maintained by plate shape change and if necessary grid improvements.
Pos. Electrode Hi Power	2.0 mm thick 165 x 130 mm 80% porous	1-Deep Tabs 2-Imp. Grid 3-Coining	Imp. Power Capability	1-Cost incr. 2-Min. Cost Increase	Alternate methods may be appropriate Deep tabs are last resort.
Neg. Electrode Hi Energy	1.2 mm thick 165 x 195 mm	2.0 mm 165 x 137 mm	Higher Energy per unit wt.	Sligh Rd. Grid savings Lower process costs.	Same process costs result in more MWH per unit volume plate
Neg. Electrode	1.2 mm thick	2.0 mm	Improved	Slight	7 mm Top portion of plate devoted to conduction
Hi Power	160 x 130 mm	160 x 137 mm W/coining	Power Capability	Increase	
Separator	0.85 mm Thickness	0.70 mm Thickness	Higher Energy Density	None	Less electrolyte per per unit capacity Aggrivates thermal problem.

4.4 Energy Balance

The nickel-iron battery operates at normal ambient temperature and pressure conditions. It will charge and discharge efficiently at initial temperature from -20 to +40°C. The battery requires no auxiliary energy expenditures to compensate for:

Start up or shut down procedures.
Shunt currents, parasitic losses or thermal effects.

The stand losses for the nickel-iron battery have been determined and are represented by the graph in section 3, Figure 3-3 of this report. Under the conditions of the simplified 24 hour driving pattern the stand losses can be applied at the rate represented by the 160 hour section of the graph. When the discharge is begun immediately after the completion of a charge cycle the rapid loss shown from zero to 40 hours does not occur. That loss is due to rapid oxygen evolution from the positive electrode which stops when the discharge is begun. The stand loss for this nickel-iron battery would be only .03% per hour under these conditions. The loss in watts during the stand periods is in proportion to the battery capacity. The data in Table 4-7 is for the 12 KWH commuter vehicle.

The total energy efficiency of the nickel-iron battery is taken as the product of voltage efficiency and the coulombic efficiency of charging. The voltage efficiency is the ratio of the average discharge voltage at the three hour rate to the average voltage for an eight hour charge. At present the coulombic efficiency is set, by the specified recharge procedure, to yield the highest output from the battery. We expect that the advanced batteries could be operated at 90% coulombic efficiency with only a small reduction in output, see Fiugre 3-8.

The data which is applicable to the battery is tabulated in Table 4-7

TABLE 4-7

ESTIMATED IN USE ENERGY CONSUMPTION

SEGMENTS

PARAMETERS	1 DRIVE	2 STAND	3 DRIVE	4 STAND	5 RECHARGE
Self Discharge		4 Watts		4 Watts	
Energy Eff.*	64% (72%)		64%(72%)		64% (72%) (56%)

*Voltage efficiency is 80% for Ni-Fe system.

( ) advanced battery, only if considered important.

(56%) represents periodic equalization recharge to recover full iron capacity. It is believed that 110% AH return would not fully recharge the iron plate.

4.5 Life Consideration

4.5.1 Present Status

The Eagle-Picher nickel-iron battery is the one "Near Term Battery" of the DOE program to exceed its life goals. Tests at the NBTL, Eagle-Picher and SU, Sweden are summarized in Table 4-8 below:

TABLE 4-8

PRESENT STATUS OF CYCLE LIFE

	CYCLE LIFE*	DEPTH OF DISCHARGE	LIFE LIMIT MECH	STATISTICAL BACKGROUND
CELLS	1500/1700	80 - 100%	xx	xxx
MODULES	1200/1700	80 - 100%		
BATTERIES	1000/1500	80 - 100%		

* Cycle life shown is demonstrated/projected.
xx Life limiting mechanisms and their correction follows in the discussion.
xxx A statistical calculation on battery reliability has not been performed.

For the purpose of this report we have confined the discussion of life limiting mechanisms to those which have been observed in the battery test programs at NBTL, EPI and S.U.

Both failure mechanisms were manifested in the first cell failures at the NBTL at about 800 cycles at 80% DOD. Post test analysis on two cells from different modules revealed sludge shorting and split separators. The sludge shorts were alleviated in two different manners. In one case the sludge space was more than doubled in height. An alternate solution was to lower the separator to contact the case bottom. This confined the sludge to the region of the negative plate which generated it. It reduced the corner and edge "build up" which caused the problem. The separator had split at the fold around the positive electrode. Positive electrode growth caused the split. The separator had already been rearranged to fold around the negative electrode which does not expand with age. No further action was taken. The separator has since been changed to flat individual sheets to eliminate the fold.

4.5.2 Projected Cycle Life

The projected cycle life is based on the separator corrections already included and further refinements more recently included in the designs. The rapidity with which sludge accumulates has been more than halved. Edge coining of the iron electrode eliminates most of the sludge. Newer cell designs accomodate the positive electrode growth. Elimination of the bottom plate support will relieve the terminal seal stress as the electrode expands. None of these changes has an impact on cost. The edge coining would be accomplished in the same operation as the tab area is coined for welding.

The difference between energy and power designs is not sufficient to have a significant effect on battery life. However, in theory the power designs should exhibit greater endurance. The power oriented batteries will have lower specific energy and internal resistance. Both tend to lower the maximum temperatures during discharge. The cooler battery will exhibit the longer life.

4.5.3 Life Effects on Battery Operating Characteristics

Actual measurements of battery operating characteristics during life cycle testing have not been made. However, the peak specific power, specific energy, efficiency, and thermal losses will be related to electrode aging. The nickel-iron battery exhibits very stable output during its useful life indicating that at moderate rates, 2 to 3 hours discharge, plate degradation is not significant. Consequently specific energy, efficiency, and the thermal characteristics of the battery will remain practically constant for the life of the battery. When peak specific power is considered the ultimate capability is being measured. This characteristic must be influenced by age since it demands that the total plate volume be effective. The iron electrode is corroded and recharged in each cycle. The reaction can not be 100% reversible. There is a reduction in peak specific power vs. cycle life. The rate at which it occurs has not been measured.

4.5.4 Reliability

In the absence of a mathematical reliability estimate for the nickel-iron battery, it is suggested that it would prove to be excellent. The battery is conventional in design and construction. It requires no auxiliaries for its operation. Each battery is performance

tested as part of the manufacturing procedure. The cycle to cycle reliability of the unit is the best possible.

At present the smallest replaceable block of cells in operating batteries is a five cell module. The modules are repairable in that plate groups in individual cells can be recased. This has been the only repair required. New batteries will incorporate polypropylene heat sealed cases. This will correct the problems caused by cemented ABS plastic cell jars.

4.6 Other Operational Characteristics

4.6.1 Special Charge Requirements

Overcharge - The Ni-Fe battery is unaffected by overcharging at low or ordinary currents. Overcharging is routine in reestablishing capacity after extended periods of shelf storage. Cells and modules have been charged at the 10 hour rate until they were completely dry without damage or reduction in subsequent performance.

Overdischarge - Forced overdischarge, as a weak cell in a battery or power discharge on a module, which causes oxygen evolution on the iron electrode will damage those plates. The Ni-Fe battery does have considerable protection against this situation by virtue of design and the chemistry of the reaction. First the cells are designed so that a 20% overdischarge is required to exceed the first plateau capacity of the electrode. The second plateau discharge, Fe^{+2} to Fe^{+3} offers in theory another 50% protection before oxygen is evolved. When it occurs this type failure of the iron is characterized by corrosion detaching the active material from the grid and plugging the fine pores in the double porosity structure of the plate. Recovery from overdischarge is dependent upon its

severity.

Cell Balancing - Not required. The normal amount of overcharge in each cycle is sufficient to cover efficiency differences.

Periodic Complete Discharge - Not required. The test programs have not indicated any problem with repeated partial discharges on this battery.

Equalization - To be determined. This type routine might be used with reduced charging return. If less than maximum performance is satisfactory, then decreased recharge levels would reduce watering frequency and increase charging efficiency. Under this type service some periodic equalization might be required to keep the iron electrode fully charged.

4.6.2 Maintenance

Charging - By proper and timely charging the user can reduce significantly the amintenance the Ni-Fe batteris require. Recharging daily after only fractional discharge reduces the charge efficiency and increases the water usage.

Watering - Typical designs require watering after five full cycles of 120-130% AH recharging. Watering frequency has been about once per week. Ultimately the watering interval might be one month.

Inspection - Monthly, to observe that watering caps are in place and not causing electrolyte salt bridges between terminals. Clean or rinse if required.

Refurbishment - Factory refurbishment of batteris is possible at fractional cost. This has already been demonstrated to replace breeched ABS cell jars. Each occasion will require individual consideration.

4.7 Packaging Flexibility

4.7.1 Volume

The volumetric considerations for the various designs are listed in Table 4-9. The volume predicted is for battery cells only. No module trays are included.

TABLE 4-9

NICKEL-IRON BATTERY VOLUME

DESIGN	ENERGY KWH	STATE-OF-ART LITERS	ADVANCED LITERS
Commuter	12	130	110
Hybrid	15	175	155
EV or Van	25	260	233
Full Perf.	50	520	446

4.7.2 Size Limitations

The conventional design of the nickel-iron battery imposes a limit on the height of a cell. In the capacities required for electric vehicles, batteries less than eight inches high would have poor volumetric efficiency. The space required above the tops of the plates becomes proportionally larger as the cell gets shorter.

The advanced designs will be about 9 inches high, because EV's will need "short" batteries and this shape improves the power capability per unit of weight.

4.7.3 Subsystems

The nickel-iron battery requires small I.D. tubing to vent battery gases to a safe location and feed make up water to the individual modules.

4.7.4 Scale Effects

The scale effects between 12 and 25 KWH batteries would be small. Table 4-9 indicates that up to 4% more volume is allowed for the smaller batteries.

APPENDIX C

DESIGN ANALYSES OF EXXON ZINC/BROMINE BATTERIES FOR VARIOUS ELECTRIC VEHICLES

DRAFT

DESIGN ANALYSES OF EXXON ZINC/BROMINE BATTERIES FOR VARIOUS ELECTRIC VEHICLES

MARCH 17, 1984

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INTRODUCTION

This report is a brief description of a series of design analyses performed by the author as part of a program being conducted by JPL to determine the feasibility of using varius energy storage and energy conversion technologies in "Advanced Vehicles" for use on US roads in the 1990's. Unlike most of the battery developments being considered in this phase of the JPL study, the zinc/bromine battery designs and the analyses thereon reported here were not the result of work done by the developer - the Exxon Research & Engineering Company. Although this unit of Exxon is a DOE developer, they declined to respond to an offer to conduct the work requested by JPL under contract from the latter. The personnel at Exxon who are involved in zinc/bromine battery development did, however, agree to aid the author in developing a response to the questions being posed by JPL in this phase of the JPL analysis. The questions being posed by JPL referred to are given in the work statements of those battery develpers who did agree to conduct the required analyses under contract, and are further delineated in the "Guidelines" sent to such contractors, and to Exxon, as part of the study. The questions and guidelines will not be reviewed further here and are incorporated in this report by reference. We must recognize that this report, unlike most of the others that will be reviewed by the technical panel assembled for this purpose by JPL (the "Review Board") has not been prepared by the battery developer but by a member of the Review Board. The time and manpower devoted to the analysis of Exxon zinc/bromine batteries is thus a small fraction of that used in analysing

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other battery systems, and that the responses are probably more conservative than might be expected from developers who have vested interests.

EXXON has been in the process of developing zinc/bromine batteries for almost a decade, although their experience with some of the components of their system extends for a substantially longer period than this. This development work has progressed to the point where relatively large zinc/bromine batteries have been assembled and tested by Exxon. Thus, both 10kWh and 20kWh zinc/bromine batteries, incorporating somewhat different design details, have been tested more-or-less successfully during the past two years. Exxon is in the process of developing, under a program funded by the Department of Energy, an electric vehicle battery that will be tested in an EV that is being developed in a parallel DOE program by Ford Motor Company. This experience with relatively large devices makes the job of projecting the performance of zinc/bromine batteries somewhat more straightforward than it might otherwise be, although we should note that the batteries that have been built and tested to date have not had the power capabilities that are believed to be needed for advanced EVs.

Exxon have been developing the electrically-conducting carbon/plastic composite materials for possible use in electrochemical devices, in collaboration with others, since the late 1960s, and the bromine complexing agents have been under development for a considerable period of time also. The initial interest in zinc/bromine batteries at the Exxon Research & Engineering Company, the unit of Exxon at which the work under discussion has

been carried out, was as potential electric vehicle candidates. Work on the system was funded exclusively by the parent company of Exxon R & E (through another unit - Exxon Enterprises) until early 1980, when Phase I of a DOE program was initiated. Since that time, Exxon has cost-shared the DOE program, and the work has been directed, until recently at least, to the development of batteries that might be applicable to solar photovoltaic system energy storage. Exxon maintained it's interest in the EV application however, and during the past year or so, a development project on EV batteries has been underway in addition to the one for solar PV batteries. Sandia National Laboratories has had responsibility for managing and/or monitoring the Exxon zinc/bromine battery programs for DOE.

The technology on which the Exxon zinc/bromine battery is based is fully described in two reports on their DOE program published by SNLA - "Development of a Circulating Zinc-Bromine Battery", Phase I Final Report, SAND82-7022, and Phase II Final Report, SAND83-7108. In essence, the Exxon zinc/bromine battery technology has the following features:

* Circulating electrolyte, with two separated flows into each cell and "flow-past" the zinc and bromine electrodes. Sculptured microporous polyolefin, "Daramic", used to separate and space zinc and bromine electrodes and to form compartments of each cell.

* Conductive carbon/plastic electrodes, high surface area carbon "attached" to the faces to be used as bromine electrodes. Carbon/plastic composites and insulating (polyolefin) edges formed by inexpensive co-extrusion method.

* Bipolar cell-stack utilizing Exxon's "shunt-current protection" to prevent maldistribution of zinc growth on cycling. Flow frames (with channels to direct flows as necessary) made by injection molding with Daramic separators as inserts in mold.

* Bromine complexing agents to store the elemental bromine formed during charge as a separate phase in a special compartment of the battery.

> Complexing agents dissolved in battery electrolyte before charge; brominated complex "carburretted" into flowing electrolyte to supply bromine during discharge.

The flow arrangement proposed by Exxon for their zinc/bromine batteries is shown in Figure 1. A photograph of the components that are used to make cell-stacks of the design currently favored by Exxon are shown in Figure 2. Exxon believes that this technology will give zinc/bromine batteries that will be reasonably high in performance and yet will be inexpensive. The calendar and cycle-life of Exxon zinc/bromine batteries is projected by them to be relatively short, however, although they believe that the low cost that will be attainable will counterbalance this short lifetime so as to give a low life-cycle-cost. The reader is referred to the reports cited above for further details of the Exxon zinc/bromine battery technology.

In the balance of this report, we will describe and discuss the answers to the questions that have been posed of various battery developers by JPL, the latest version of these questions, as described in the "Guidelines" described above, being addressed. In the next section - METHODOLOGY OF THE STUDY - we will describe the methodology used in making the quantitative and qualitative estimates asked for by JPL. The third section - STUDY RESULTS - will give the answers to the questions posed by JPL in the last version of the guidelines. The fourth and final section will deal with the VALIDITY OF THE ESTIMATES and in it we will discuss the answers to the JPL questions that were derived from the information given to us by Exxon.

METHODOLOGY OF THE STUDY

In the "Guidelines" sent to battery developers, JPL indicated that there were eight vehicle types for which they would like preliminary designs to be made. From these preliminary designs, it was hoped that battery developers could make reasonably reliable projections of the specific energy, specific power, volume and OEM price of batteries that would give the desired EV performance. It was recognized from the beginning that any particular battery on which information was being sought would not necessarily meet the requirements of all eight vehicle types specified by JPL. In the present study, we decided to eliminate vehicle types for which we thought that zinc/bromine batteries would be inherently unsuitable. Additionally, we combined some vehicle types for which the battery requirements were very similar. The EV types and battery requirements on which we hoped to develop outline designs were, therefore, as follows:

* Two-passenger commuter EV	12kWh	25kW
* Hybrid 4/5-passenger EV	15kWh	50kW
* General purpose electric car or van	25kWh	60kW
* Full performance 4/5-passenger EV	50kWh	50kW

We note at this point that the present design for a zinc/bromine EV battery leads to nominal ratings of about 20kWh and 30kW.

Ideally, we had hoped to answer the questions posed by JPL in the "Guuidelines" by making projections of battery performance on the basis of

actual preliminary designs for zinc/bromine batteries optimized to the four vehicle types listed above. However, since Exxon did not find it possible to accept a contract from JPL to perform such work, it was necessary for us to adopt a different approach. The methodology we used to make the necessary projections therefore consisted of the following steps:

* Careful review of the literature available on the design of Exxon zinc/bromine batteries for electric vehicle use.

* Development of a set of forms (attached as Appendix A) to facilitate recording information received from battery developers who agreed to respond to the JPL "Guidelines".

* Quantification of the weight, volume, projected OEM price and expected performance of the present state-of-the-art battery.

* In face-to-face and telephone discussions, and written communications with Exxon personnel, establishment of projections for the performance, weight, volume and OEM price of a zinc/bromine battery with an optimized present-day design.

* Acquisition of information on the non-quantifiable questions in the JPL "Guidelines" by face-to-face questioning of Exxon personnel.

* Acquisition of the coefficients of the Symons Equations for the weight, volume and OEM price of batteries with performances different from those given to us for the optimized present-day design. This information was requested of Exxon personnel during our meeting and received in writing at a later date. For a further discussion of the Symons Equations, see below.

* Calculation of the weight, volume and expected OEM price of Exxon zinc/bromine batteries for the four vehicle types listed above, and calculation and projection of the specific energy, specific power and battery OEM price projections requested by JPL. Note that the specific energy versus discharge rate and specific peak power versus state-of-discharge projections were made on the basis of the overall weight projected for the various batteries combined with the projected performance of the optimized present-day design battery.

* Submission of the final projections to Exxon by way of a first draft of this report and modifications of the projections as necessary through telephone conferences with their personnel and by means of written communications from them.

It should be noted that a zinc/bromine battery of the type specified in the

"Guidelines" as "Present" has not yet been built by Exxon, and that the projections given under this heading in the next section have been made on the basis of the performance of a 20kWh battery designed for solar PV storage. This approach was taken because the final design details of the zinc/bromine battery to be built under the DOE/EHV/Ford project have not yet been determined, and use of the expected performance, weight and volume characteristics of this battery would therefore be premature.

The Symons Equations, referred to above, that represent an inherent part of the projection methodology used in the present study, were derived by the author as part of a study conducted by Argonne National Laboratory. The derivation of the equations was described in detail in an internal report to ANL (1982) and has been summarized in a number of open-literature publications (see, for example, P. C. Symons, Extended Abstracts of the Electrochemical Society, Volume 82-2, pg. 7). In essence, the formulae that are now described as the Symons Equations relate the weight, volume and projected OEM price of a battery to the energy and power that are to delivered by it. The three equations are as follows:

$$\text{Battery weight } (W) = A \times E + B \times P + C$$

$$\text{Battery volume } (V) = A' \times E + B' \times P + C'$$

$$\text{Battery price } (X) = A'' \times E + B'' \times P + C''$$

- where E is the energy to be delivered by the battery to the motor-controller of EV in kWh, P is the power required to give accelerations in kW, and A, A', A", B, C etc. are coefficients that are derived from a particular battery design. The energy and power used in the Symons Equations must be specified

carefully if the equations are to be useful (see references for a further discussion of this). Please note that the coefficients of the Symons Equations refer to a particular group of batteries that are designed according to the same set of principles; these equations cannot be used for batteries of the same generic type at different stages of development. Any particular set of coefficients refer, of course, to batteries of the same generic type. In addition, it should be noted that the Symons Equations are only intended for use over relatively small ranges of energy and power. The ranges appropriate for any particular set of Symons Coefficients will depend on the battery type and the actual battery design that was used to derive them. The use of estimating formulae such as the Symons Equations to project the performance or price must never be taken out of the context in which the coefficients were derived.

The methodology used to estimate the characteristics of various zinc/bromine batteries that has been used herein necessarily results in projections that are based on the same set of critical design and performance assumptions. In other words, we do not assume different degrees of success in developing the various batteries required for different vehicle types. Improvement over the present state of the art is assumed, however, as will be discussed in the final section of the report. In the next section, we describe the results of the design analysis that has been performed on Exxon zinc/bromine batteries.

STUDY RESULTS

As described in the preceding section of the report, the information on Exxon zinc/bromine batteries for the JPL study has been received in two separate ways. Firstly, during a visit to Exxon, the author got projections on the expected performance, OEM price and life characteristics of an EV battery with a design which is basically an optimized version of the one presently under development for solar PV storage. Information on batteries designed specifically for the EVs of interest to JPL was not available directly but was obtained in the form of coefficients for the Symons Equations. These coefficients, supplied in writing to the author, represent the second way in which the information required for the JPL study was obtained. We note that the two types of information obtained from Exxon are supposed to refer to batteries designed according to the same basic design principles and that different degrees of advancement of the technology are not assumed for the various EV types. Both types of information obtained is summarized below, this being presented as completed "JPL Forms" (see preceding section) at the end this section. A commentary on the assumptions believed to have been used by Exxon is given first, and then the values of the coefficients of the Symons Equations are described and discussed, before the overall information requested by JPL is given.

The design basis on which the quantitative information given below was calculated or projected is as follows:

* Overall system designed according to the principles of Exxon zinc/bromine batteries outlined in the INTRODUCTION to this report and described in Exxon's SNLA reports referenced above.

* Fully charged electrolyte has composition comprising 3 molar zinc bromide, 0.5 molar each of MEMBr and MEPBr (bromine complexing agents), 4 molar of a mixture of potassium and ammonium bromides.

* Utilization of dissolved zinc, ie. fraction of zinc that would be plated during a full charge with a 100% coulombic efficiency, taken as 70% for all designs. This implies that the minimum concentration of zinc bromide will be about 0.9 molar, neglecting the coulombic inefficiency and any volume change of the electrolyte that may occur.

* Baseline (ie."Present") design based on a charge zinc loading of 90mAhr/sq.cm. and a charge time of 3 hours. The Exxon method used to make calculations of battery weight as a function of expected capability is shown in Table 1. EV battery designs with a different P/E ratio would have a different loading and charge time.

* Values of energy deliverable given for a continuous discharge at the stated rate, such discharge immediately following the preceding charge. Values for energy deliverable do not, unless otherwise stated, include the energy required for auxiliaries - pumps and shunt current protection - during discharge. The actual energy that can be delivered must be reduced by the energy required to drive the auxiliaries during the discharge.

* The "Present" design gives a nominal 20kWh and 30kW battery that is projected to weigh 303 kg. and to occupy 284 litre. A breakdown of the weight and volume of this battery is shown in Table 2. A 20kWh battery with an unoptimized design of the same type as that used for the projection actually weighs 330kg. However, the power of this battery is not as high as that projected for the "Present" design. A new cathode layer (CP-3), already under test in small cell-stacks, is thought to be capable of the required performance.

* The energy deliverable under sustained discharge was projected by Exxon on the basis of data obtained on Stack # PAM01Z, this being designed and tested according to the principles listed herein. Experimental discharge curves for this cell-stack are given in Fig 3.

* Projections for peak power capability of the "Present" battery were made by Exxon on the basis of data obtained on a 10kWh cell-stack identified as Z-10. This stack has a design similar to that assumed in making the projections. The raw data used in making the projections is shown in Fig 4. The state-of-charge (SOC) is defined relative to the energy deliverable (see above) at the three-hour discharge rate.

* Estimates of the OEM price of an Exxon zinc/bromine battery of 20kWh

nominal capacity were made by the developer according to the ADL method in 1981. The results of this Exxon analysis are given in the Phase II SNLA Report referenced above, and are summarized in Table 3. The battery costed is presumably of the same design as that for which weight and volume estimates are given above. An OEM price of about $800 for the 20kWh battery resulted from this estimate.

These design principles represent the basis for projections made for the "Present" design battery and for batteries with different performance capabilities.

For batteries that are required to have capabilities different from the baseline ("Present") design, Exxon submitted coefficients for the Symons Equations to the author. Thus, the following formulae were projected by Exxon to be applicable to the calculation of the weight, volume and OEM price of the zinc/bromine batteries required for the EV applications being analysed by JPL:

Weight	=	kWh x 12.3	+	kW x 1.35	+	38.3	kg
Volume	=	kWh x 12.3	+	kW x 1.36	+	99.8	litre
OEM Price	=	kWh x 16.0	+	kW x 4.58	+	344.3	1981$

- where kWh represents the energy that can be delivered by the battery at the three hour rate and kW is the peak power deliverable at 30% SOC. It should be noted that these definitions of the energy and power are not the same as those used in deriving the Symons Equations, and as a result, some further care should be taken in applying the formulae than normally is needed.

In deriving these formulae, we understand that Exxon assumed that changes to the power capability of a battery could be achieved by adding or removing individual bipolar electrodes and their associated frames, separators and electrolyte to or from baseline design, and that the energy could be changed

by means of changes to the amount of electrolyte in the battery. The weight, volume and OEM price formulations then follow from the breakdowns referenced above and the assumed performance (20kWh, 30kW) of the baseline design. On the basis of these assumptions, the sustained and peak power projections asked for by JPL for batteries other than the baseline case can be derived by using ratios from the values projected for the baseline design.

The projections requested in the latest version of the JPL "Guidelines" are given in Tables 4 to 12. The quantitative projections given in these tables should be only used in EV optimization calculations in conjunction with the background information in this report. In the tables, there is some information that is referred to by means of numbered notes. These notes follow and should also be used in conjunction with the projections in the tables.

Note 1: Energy consumption by the items shown in Table 8 (pumps, shunts, self-discharge, etc.) should be regarded as proportional to the nominal power of the battery.

Note 2: There has not, as yet, been a great amount of formal cycle-life testing conducted at Exxon on zinc/bromine batteries. The life of the active carbon layers now used is not known at present. Reliability of small flow battery systems is of some concern because of the pumps and other mechanical components.

Note 3: The volume of the baseline 20kWh/30kW battery calculated from the Symons Equation given to the author by Exxon is 384 litre. This value does not coincide with either of the volumes given for this battery during the meeting with Exxon. This is troublesome because the volume of Exxon

zinc/bromine batteries is one of the principal concerns in EV applications.

The values given for the characteristics of Exxon zinc/bromine batteries designed for EV use in this section are those given to us by Exxon personnel during a meeting and/or in writing. The validity of the estimates made in this section is discussed in the next and last section of the report.

VALIDITY OF THE ESTIMATES

THIS SECTION WILL BE WRITTEN FOLLOWING FURTHER DISCUSSIONS WITH EXXON, PATICULARLY AFTER THEY HAVE HAD A CHANCE TO REVIEW THE PRECEDING SECTIONS OF THE REPORT.

Table 1. 20 KWh Battery Design Calculations

- Basis: 90 mAh/cm^2 Zn loading
  70% Zinc utilization
  80% Coulombic Efficiency
  3M $ZnBr_2$ Electrolyte

- Electrolyte Volume and Weight

$$\text{Volume} = \frac{(\text{electrode area})\ (\text{Zn loading})}{(\text{zinc concentration})\ (\text{zinc utilization})}$$

$$= \frac{(1160\ cm^2/\text{electrode})(156\ \text{electrodes})(.090\ mAh/cm^2)(3600\ s/hr)}{(2 \times .965 \times 10^5\ As/\text{mole})(3\ \text{mole Zn/liter})(.7\ \text{utilization})} =$$

$$= 147.7\ l$$

Weight = 147.7 l x 1.7 kg/l = 245.9 kg

- Capacity

Capacity = (Zn loading)(av. discharge voltage)(coul. effic.)(electrode area)

= (.090 Ah/cm^2)(1.676V)(.8 coul. eff.)(1160 cm^2/electrode)(156 electrodes

= 21.8 kWh gross

Net Capacity = Gross Capacity - Auxiliary = 21.8 - 3.1 = 18.7 kWh

- Power (50% SOC at 70% of OCV)

Power = (voltage)(current density)(electrode area) =

(1.232V) (.189 A/cm^2)(1160 cm^2/electrode)(156 electrode) = 42.0 kW

- Base Case (20 kWh, 90 mAh/cm^2, 70% utilization)

$$\text{Energy Density} = \frac{18.7\ kWh}{325\ kg} = 57.5\ Wh/kg$$

$$\text{Power Density} = \frac{42\ kWh}{325\ kg} = 129\ W/kg$$

Table 2. 20 kWh EV/PV DESIGN - INVENTORY - WEIGHT AND VOLUME BREAKDOWN

Component	Part Dimensions (cm)	Number of Parts (#)	Volume (liter)	Density (gm/cm^2)	Weight (kg)	Totals Volume (liter)	Totals Weight (kg)
Stacks		2	97.5*		48.7	97.5	48.7
Bipolar Electrode	36.5 x 51 x .06	154	17.2	.9	15.5		
Current Collectors	36.5 x 51 x .10	4	.7	.9	.7		
Separators	36.5 x 51 x .21	156	61.0	.9	24.1*		
Neg. Feed Blocks	36.5 x 51 x 2	2	7.4	.9	3.3*		
Pos. Feed Blocks	36.5 x 51 x 3	2	11.2	.9	5.0*		
Tie Rods	53 x .65 D.	4	.02	7.9	.1		
Electrolyte			144.7	1.55	245.9		224.3
Reservoir			106.7			106.7	
Stacks			38.0				
Auxiliaries/Misc.			80.2		30.2	80.2	30.2
Pump Heads	8 x 8 x 8	2	1	.2†	.2		
Pump Motors	8 x 8 x 12	1	.8	4.0†	3.0		
Valves	4 x 6 x 12	2	.6	.4†	.2		
Plumbing	100 x 3 D.	4	.6*	1.0†	.6		
Controller	5 x 5 x 1	1	-	.2†	-		
Heat Exchanger	40 x 45 x 4	1	7.2	.2†	1.4		
Fan (HX)	30 x 30 x 20	1	18	.1†	1.8		
Pump (HX)	10 x 10 x 10	1	1	.2	.2		
Coolant	-	-	6	1.1	6.6		
Sensors	-	-	-	-	.2		
Insulation/Packaging	3.5 M^2 x 1	1	35	.2	7		
Voidage	-	-	?	-	0		
Tankage/Supports	-	-	10	.9	9		
					Totals	284.4	303.2

*Void Volume Adjustment

†Void Volume Adjustment

Table 3. Total Factory and Capital Costs

Material (Includes Electrolyte @ \$220/Module)	\$ 321.36
Purchased Components (Includes Outside Molding Costs and Accessories)	211.71
In-House Labor Costs	68.74
Total Material, Components & Labor Cost/20 kWh Module	601.81
Total Material, Components & Labor Cost/kWh	30.09

1. @ 2500 MWh Material, Components & Labor Cost per Year	\$75,225,000.00
2. Marked-up Equipment Costs (10% of estimated (\$12,500,000)	1,250,000.00
3. Rent (100 sq. ft. Plant @ 5.00/ft^2)	500,000.00
4. Total Factory Costs (Lines 1 + 2 + 3)	76,975,000.00
5. Working Capital Requirement (30% line 4)	23,092,500.00
6. Total Investment (\$12,500,000 + line 5)	35,592,500.00
7. Return on Investment & Taxes (30% line 6)	10,677,750.00
8. Additional @ \$5.00/kWh	12,500,000.00
9. Total Capital Cost (lines 4, 7 & 8)	100,152,750.00
Capital Cost per 20 kWh Module	801.22
Capital Cost per kWh	40.06

- Net Capital Costs Following Page -

Table 4. Forms for Recording Information for JPL

January/February, 1984 - Page 1

DATE: 03/18/84 LOCATION: EEC, Inc.

DEVELOPER: Exxon SYSTEM: Zn/Br_2

1. PERFORMANCE MODELING

(a) Battery discharge characteristics:

Battery Design	Specific Energy (Wh/kg) vs Discharge Rate 20 W/kg	60 W/kg	80 W/kg	100 W/kg	200 W/kg	
1. Present,	64	55	48	41	Not Sustain-able	W/O[a]
20 kWh/30 kW 325 kg	60	52	45	38		W
2. Commuter, 12 kWh/25 kW 220 kg	55					W/O
3. Hybrid, 15 kWh/50 kW 290 kg	52					W/O
4. Electric Vehicle or Van, 25 kWh/60 kW 427 kg	59					W/O
5. Full-Perf., 50 kWh/50 kW 721 kg	69					W/O

[a]W/O and W signify Without and With Auxiliaries.

Table 5. Forms for Recording Information for JPL

January/February, 1984 - Page 2

DATE: 03/18/84 LOCATION: EEC, Inc.

DEVELOPER: Exxon SYSTEM: Zn/Br_2

1. PERFORMANCE MODELING

(b) 30-second peak specific power capability:

Battery Design	Peak Specific Power (W/kg) vs State-of-Charge			
	80% SOC	50% SOC	30% SOC	10% SOC
1. Present, 20 kWh/30 kW	146	120	100	75[a]
2. Commuter (See text)				
3. Hybrid (See text)				
4. Electric Vehicle or Van (See text)				
5. Full-Perf. (See Text)				

[a]By extrapolation.

Table 6. Forms for Recording Information for JPL

January/February, 1984 - Page 3

DATE: 03/18/84 LOCATION: EEC, Inc.

DEVELOPER: Exxon SYSTEM: Zn/Br_2

2. COST PROJECTIONS

Estimated production price to OEM @ 100,000 batteries/year

Battery Design	1981 $/battery	Basis of Estimate/Comments
1. Present, 20 kWh/30 kW	802	Phase II Report
2. Commuter, 12 kWh/25 kW	651	Symons Equations
3. Hybrid, 15 kWh/50 kW	814	Symons Equations
4. Electric Vehicle or Van, 25 kWh/60 kW	1019	Symons Equations
5. Full-Perf., 50 kWh/50 kW	1374	Symons Equations

Table 7. Forms for Recording Information for JPL

January/February, 1984 - Page 4

DATE: 03/18/84 LOCATION: EEC, Inc.

DEVELOPER: Exxon SYSTEM: Zn/Br_2

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3. TECHNICAL SUPPORT FOR PROJECTIONS

How are improvements assumed in all the above to be achieved?[a]

Component

Present Status

Design Change

Performance Change

Cost Change

Comments

[a]See text of report.

Table 8. Forms for Recording Information for JPL

January/February, 1984 - Page 5

DATE: 03/18/84 LOCATION: EEC, Inc.

DEVELOPER: Exxon SYSTEM: Zn/Br_2

4. IN-USE ENERGY CONSUMPTION[a]

Quantification of sinks of energy consumption other than those accounted for by performance modeling:

Segment /Parameter	Estimates of in-use energy consumption, W or Wh 1	2	3	4	5
Start-up and shut-down	Pumps On Continuously, 44 min.	Pumps off Stack Shorted,	Pumps on (See 1)	Pumps off, till charge. (See 2) Charge 2h at end of period	
1mA h/cm^2	3 Wh	312 Wh	3 Wh	312 Wh	3 Wh
Self-discharge					
$3mA/cm^2$	688 Wh	0	688 Wh	0	2156 Wh
Shunt currents					
	161 Wh	0	161 Wh	0	520 Wh
Parasites					
Electrolyte Pumps	95 Wh		95 Wh		260 Wh
Cooling Fan	0	0	0	0	100 Wh
Cooling Pump	15 Wh		15 Wh		40 Wh
Thermal loss					
	0	0	0	0	0
Charge eff.	Regen.	NA	Regen.	NA	Charge
Voltaic Effs only	90%		90%		87%

[a]Above based on 20 kWh/30 kW "Present" design. See Note 1.

Table 9. Forms for Recording Information for JPL

January/February, 1984 - Page 6

DATE: 03/18/84 LOCATION: EEC, Inc.

DEVELOPER: Exxon SYSTEM: Zn/Br_2

5. LIFE CONSIDERATIONS

(a) Present status of cycle life.

	Cycle life	Depth-of-discharge	Life-limiting mechanisms	Statistical background
Individual cells cannot be tested				
8-cell-stacks	~400	100%	Warpage Failed Current Collector	10
8-cell-stack				
Thicker Electrodes	640	100%	Still under test	1
Electrolyte	1200	100%	None Detected	1
Batteries				
10 kWh Sub-scale	~100	100%	Did not fail Taken apart	1 + 1 on test
20 kWh Full size	None		Cycle tested to date	

(b) Projected cycle life, approach to solving failure modes, effects of these on cost. Specify any differences between high-energy & high power designs.

1000 Deep Cycles Projected. Approaches to get this TBD.

(c) Life effects on specific power & energy, efficiency and thermal characteristics (i.e., linear with cycling).

Slow decline in efficiency, possibly lower deliverable capacity.

(d) Estimate of reliability of smallest replaceable block of cells, failure modes, mean-time-to-failure, etc.

Don't know

See Note 2.

Table 10. Forms for Recording Information for JPL

January/February, 1984 - Page 7

DATE 03/18/84 LOCATION: EEC, Inc.

DEVELOPER: Exxon SYSTEM: Zn/Br_2

6. OTHER OPERATIONAL CHARACTERISTICS

(a) Special charge requirements:

What happens if cells are overcharged or overdischarged?

No permanent damage.
See Note 3.

Is individual cell balancing required? If so, how & how often?

No

Is periodic complete discharge required? If so, how & how often?

Yes. TBD - thought to be 20 to 100 cycles.

Is equalizing necessary? If so, how & how often?

No

(b) Maintenance requirements?

What regular maintenance is required? How often?

pH (?), Air (?), Inerts Venting (?), Check Pumps and Motors (?)

What potential exists for periodic battery refurbishment rather than replacement? How does this compare to cost with replacement?

Stacks replaceable in principle, pumps/motors could be serviced. Battery could be repaired. Cost of repair labor (unknown now) will determine if done.

Table 11. Forms for Recording Information for JPL

January/February, 1984 - Page 8

DATE: 03/18/84 LOCATION: EEC, Inc.

DEVELOPER: Exxon SYSTEM: Zn/Br_2

7. PACKAGING FLEXIBILITY

(a) Estimated volume of each of the designs:

	Battery	Liters	Comments
1.	Present, 20 kWh/30 kW	300 31-5/8 in. x 25 in. x 34 in. 440	Based on component volumes Design Envelope for Battery
2.	Commuter, 12 kWh/25 kW	281	From Symons Equations See Note 3
3.	Hybrid, 15 kWh/50 kW	352	From Symons Equations See Note 3
4.	Electric Vehicle or Van, 25 kWh/60 kW	489	From Symons Equations See Note 3
5.	Full-Perf., 50 kWh/50 kW	783	From Symons Equations See Note 3

(b) Size limitations, minimum possible measurements of battery cells or modules (H x W x L), primary considerations if change must be made from present configuration, other?

Minimum height of 6 in. in reservoir. Assymmetry of electrodes 3:1. Change from present dimensions will mean redesign.

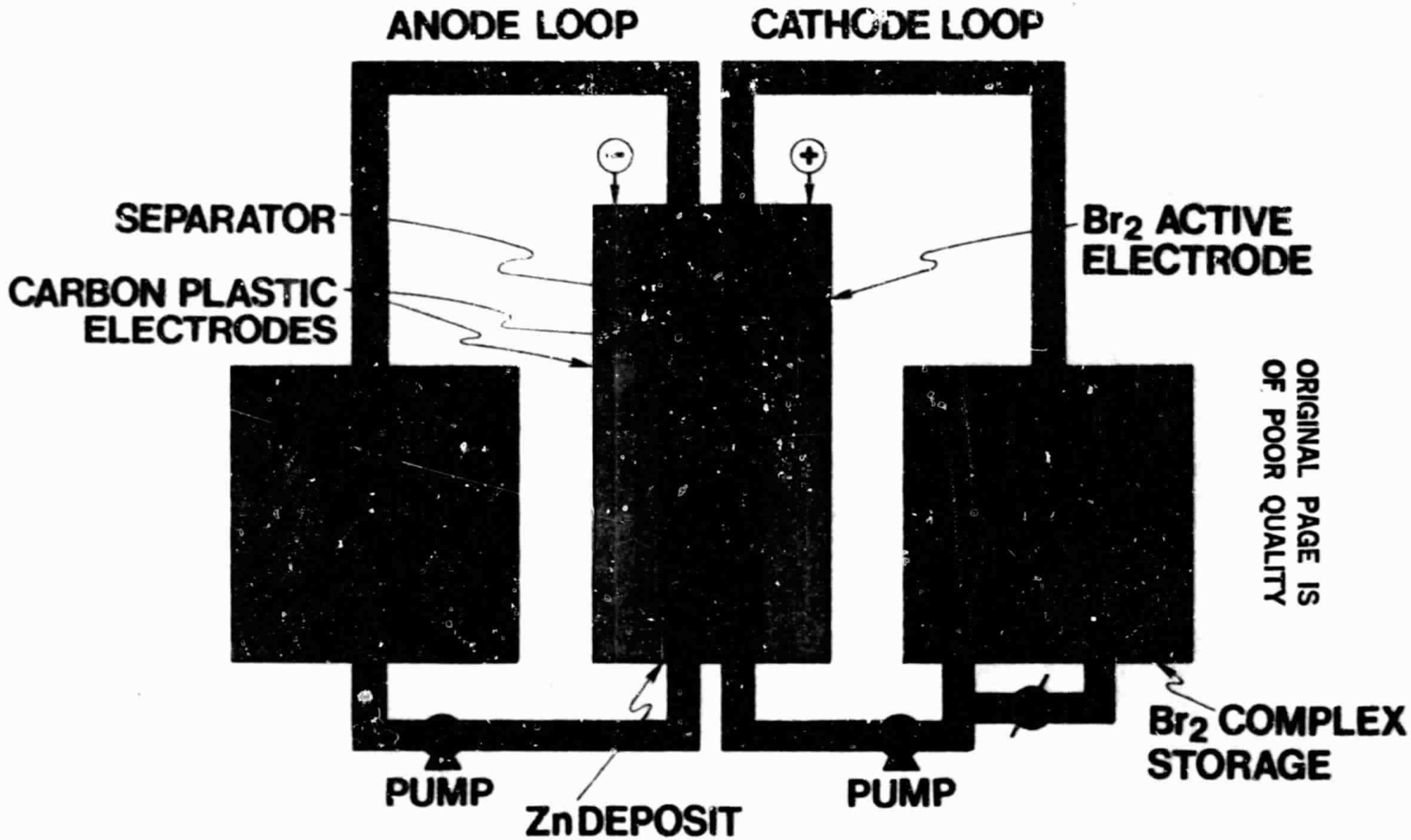
(c) Any special consideration for relative placement of components/sub-systems, i.e., necessity to place fluid reservoir near cell-stack?

Reservoir and stack(s) on same level, to keep volume at minimum. Reservoir and stack(s) could be separated.

(d) Scale effects in the 10-50 kWh range, if applicable?

Larger batteries were advantageous - even more than shown by volumes above.

ZINC-BROMINE CIRCULATING BATTERY



Electrochemical Reactions: $Zn^{\circ} \rightleftharpoons Zn^{++} + 2e^{-}$

$Br_2 + 2e^{-} \rightleftharpoons 2Br^{-}$

Self discharge: $Zn^{\circ} + Br_2 \longrightarrow ZnBr_2$

Figure 1. Circulating Zinc-Bromine Battery

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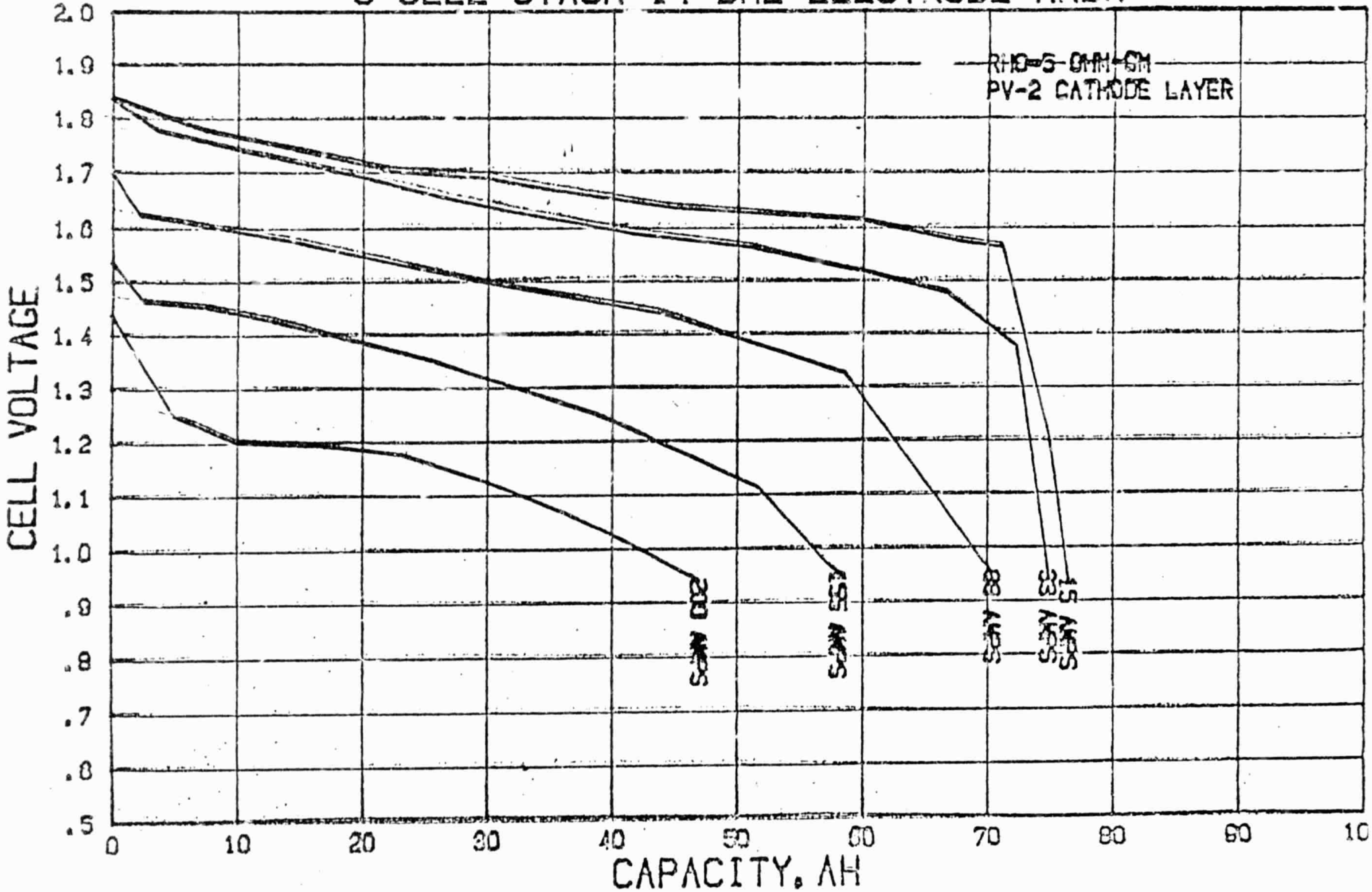
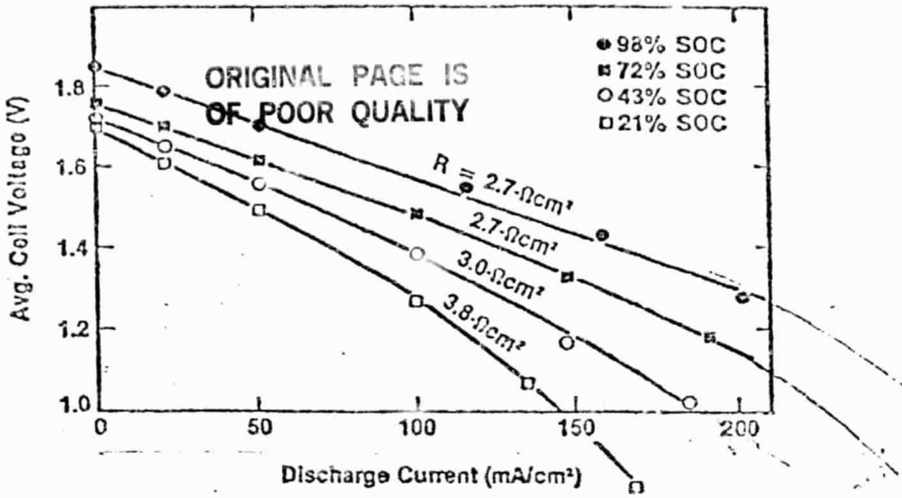
Figure 2. Zinc-Bromine 1200-cm^2 Battery Components

Figure 3. ZN-BR2 1KWH BATTERY STACK-PAM01Z
8 CELL STACK-11. DM2 ELECTRODE AREA

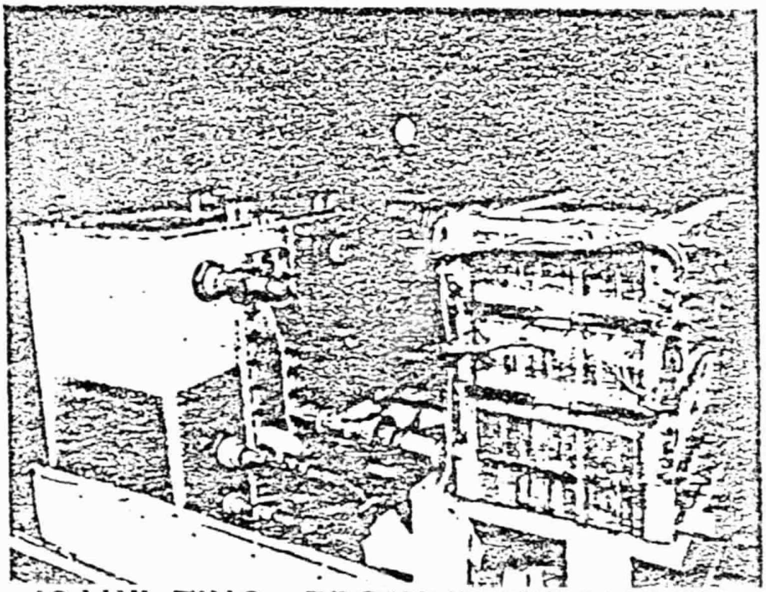


a



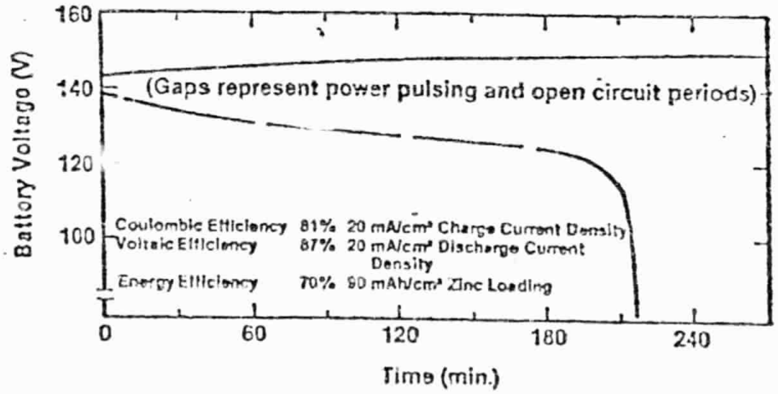
CHARGE-DISCHARGE VOLTAGE PROFILE OF 10 kWh (Z-10) BATTERY

b



10 kWh ZINC—BROMINE SUB-MODULE 120V-1200 cm² ELECTRODES

c



POLARIZATION CURVES OF 10 kWh BATTERY (Z-10) (20 SECOND PULSES)

Figure 4.

APPENDIX D

DESIGN ANALYSES OF
ZINC-CHLORIDE BATTERIES
FOR ELECTRIC VEHICLES

Prepared for
California Institute of Technology
Jet Propulsion Laboratory
Under Contract No. 956811

DESIGN ANALYSES OF ZINC-CHLORIDE BATTERIES FOR ELECTRIC VEHICLES

- - - - -

T. Hacha, Manager
Electric Vehicle Programs

March 1984

Energy Development Associates
(A Gulf+Western Company)
1100 W. Whitcomb Avenue
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EDA PERSPECTIVE

This report describes the characterization of the zinc-chloride batteries for a variety of electrical vehicle missions, with specific emphasis on the fixed power to energy batteries defined in this contract with JPL. The fixing of the power and energy levels does not allow the trade-offs of battery stored energy (vehicle range) and total vehicle weight for a particular vehicle type. This trade-off is a very important characteristic for flowing electrolyte batteries, such as the zinc-halogen systems. In the case of the zinc-chloride battery, incremental energy can be stored for a given power level at a cost of \$10/ kWh and at a very high incremental energy density of 220 Wh/kg. A graphic example of this is the general purpose van having a 60-kW, 25-kWh battery defined in this contract. A zinc-chloride battery as per these specifications would weigh 399 kg and sell for \$3,684. In reality, however, the range of this vehicle could actually be doubled for an increase in selling price of only \$250 and a weight increase of 250 pounds. This increased stored energy has to be considered as a very attractive option, since the 100-mile plus range it would allow, will greatly improve the usefulness of such a van. The subject of incremental stored energy has not been specifically addressed in this report because of the fixed power to energy definition. However, this subject is an important element in quantifying the zinc-chloride battery for vehicle market applications and must be taken into account if an accurate and comprehensive assessment is to be made.

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CONTENTS

INTRODUCTION

Energy Development Associates has been developing zinc-chloride batteries for electric-vehicle applications since 1972. By early 1976 it had developed the comb-type bipolar stack structure. Under an RD&E contract with the U.S. Department of Energy, EDA developed and demonstrated a 36-kWh engineering prototype battery in a Volkswagen Rabbit by 1980. Early in 1980 Gulf+Western Industries (G+W) -- EDAs parent company -- initiated its own program to demonstrate 40-kWh zinc-chloride batteries in specially-designed four-passenger vehicles. Upon demonstrating the technical viability of zinc-chloride powered passenger vehicles -- the Rabbit exhibiting a 117-mile range at average speeds above 40 mph in highway/city driving and a four-passenger G+W vehicle exhibiting a 200-mile range at 40 mph on a 2.5-mile oval track --, the emphasis was shifted to delivery vehicle battery development and engineering. In 1983 EDA demonstrated a 40-kWh engineering prototype battery in a converted half-ton Renault Trafic van. During independent testing of this vehicle at Ohio's Transportation Research Center, it exhibited a 90-mile range at an average speed of 35 mph.

The basic objective of this contract -- Contract Number 956811 with the California Institute of Technology, Jet Propulsion Laboratory (JPL) -- is to assess and report on the design flexibility, cost sensitivity, and technical feasibility of zinc-chloride battery designs targeted for development through the early 1990s. In preparing this report EDA has made every effort to follow the guidelines established by JPL. It should be noted however, that zinc-chloride batteries have some unique features which the pre-established guidelines fail to bring out. Many of these features are common to flow batteries and will be touched upon as a prelude to the main body of this report.

Design and Operational Description

Figure 1 schematically illustrates the operation of a zinc-chloride battery during charge. A pump is used to circulate electrolyte through the battery stack. The chlorine gas formed during charge is transferred from the stack to the store using a gas pump. The chlorine is mixed with chilled store liquid at the inlet to the pump and chlorine hydrate is formed in the pump and at the outlet from the pump. The circulating store liquid is separated from the solid hydrate particles using a filter shown at the bottom of the store. A heat exchanger utilizing glycol or Freon is used to chill the recirculating store liquid.

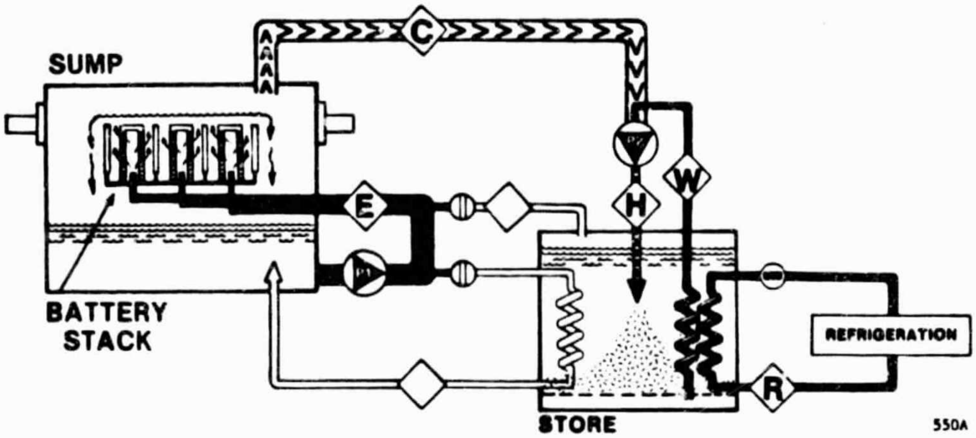

Figure 1. Zinc-Chloride Battery During Charge

Figure 2 shows the battery during discharge. Electrolyte is again circulated through the stack using a pump. A portion of this warm electrolyte is tapped from the main manifold and flowed through a heat exchanger to decompose the hydrate. The evolved chlorine gas from the store is injected and dissolved in the electrolyte stream which is feeding the stack. The gas pump is not used during discharge.

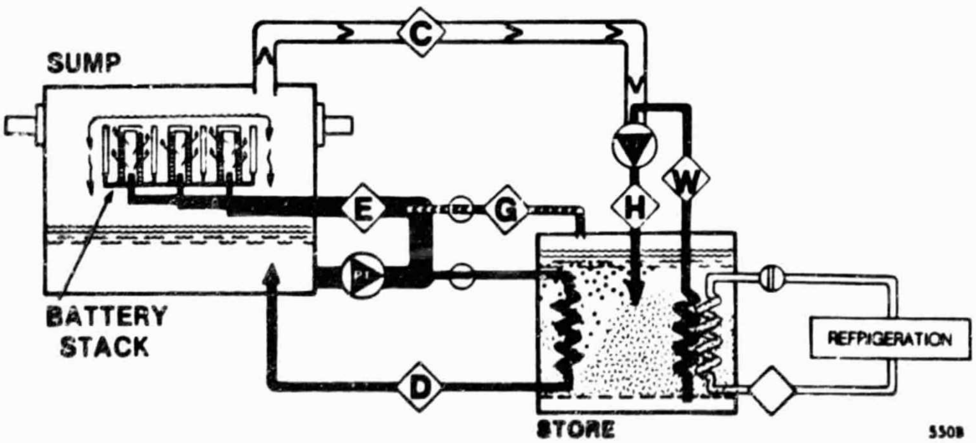

Figure 2. Zinc-Chloride Battery During Discharge

Figures 1 and 2 show the battery stacks inside the sump. In most vehicle batteries, the battery stacks are actually packaged separately from the sump and are connected to the sump by electrolyte supply and return piping. Also heat transfer between stack and store is most frequently accomplished by a direct interchange of electrolyte between the two compartments.

Figure 3 shows the present construction of a zinc-chloride comb-type battery stack. Graphite wafers, which serve as the zinc-electrode substrates, are press-fitted into one side of a bipolar busbar. Pairs of chlorine electrodes are press-fitted into the other side of the busbar. The result is a double-sided comb, hence the comb-type designation. In assembling the battery stacks, the zinc electrodes of one comb interleave with the chlorine-electrode pairs of another comb to form the unit cell. The stack terminates with a thick graphite busbar at one end with chlorine electrodes, while at the other end, there is a thick graphite busbar with zinc-electrode substrates.

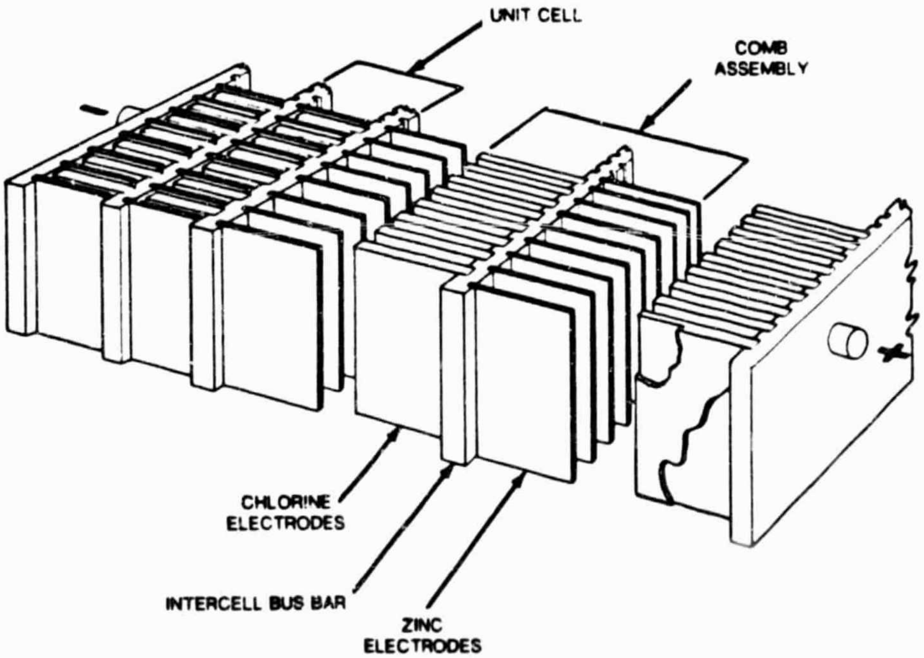

Figure 3. Zinc-Chloride Unit Cell Construction

Design Flexibility of Zinc-Chloride Mobile Batteries

Design parameters that reflect the performance and cost of zir--chloride batteries in mature production in the early 1990s were utilized to develop the relationships between power, energy, weight, and cost of vehicle batteries.

Figure 4 shows the general relationship between specific power and specific energy for P/E ratios of 1:1 to 2:1. The band illustrates that the relationship varies with different battery capacities. P/E ratios greater than 2 would be achieved by adding more stack volume.

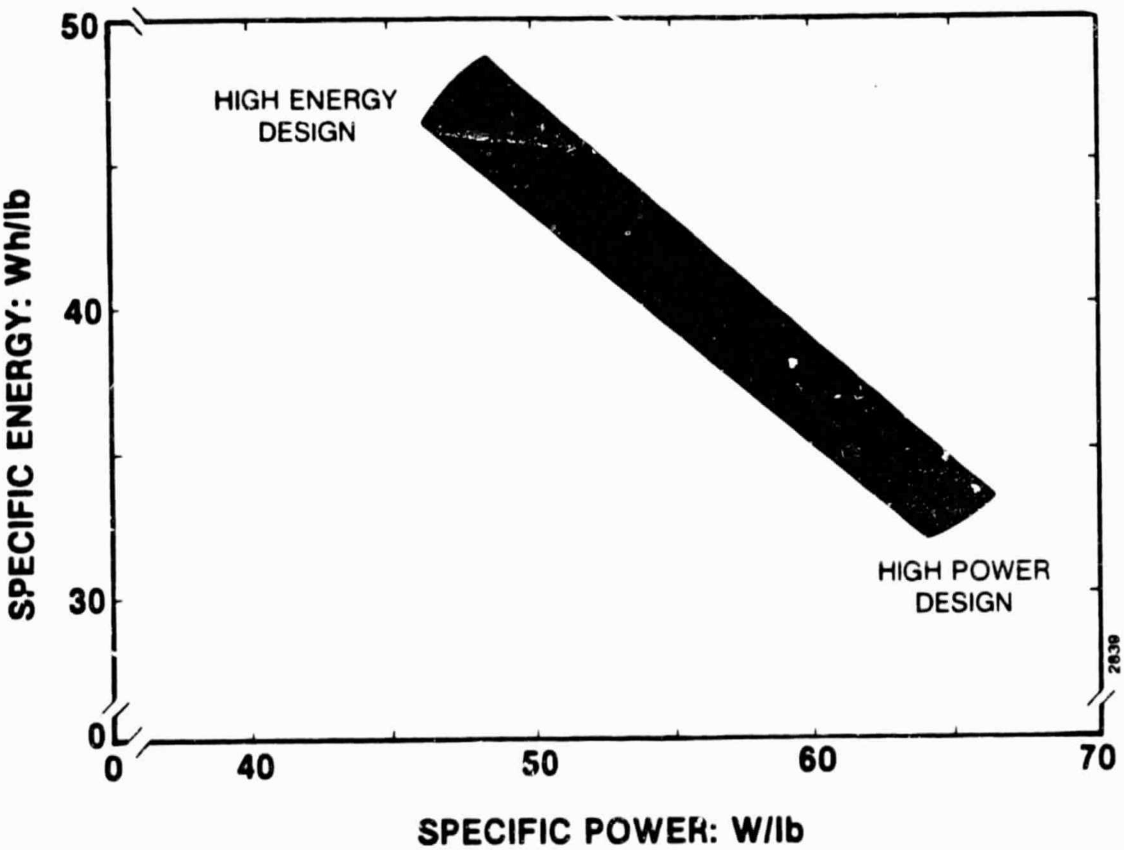

Figure 4. Specific Power and Specific Energy Relationship

Figure 5 illustrates the relationship between battery power, energy, and weight. This figure more clearly shows the effect of battery power on weight. Doubling the power of a 30-kWh battery from 30 kW to 60 kW, the weight increases from ∿660 pounds to ∿930 pounds (100 Wh/kg to 70 Wh/kg, respectively). By increasing the battery energy for any design power level increases the battery weight at a rate of only ∿10 lb/kWh (4.5 kg/kWh).

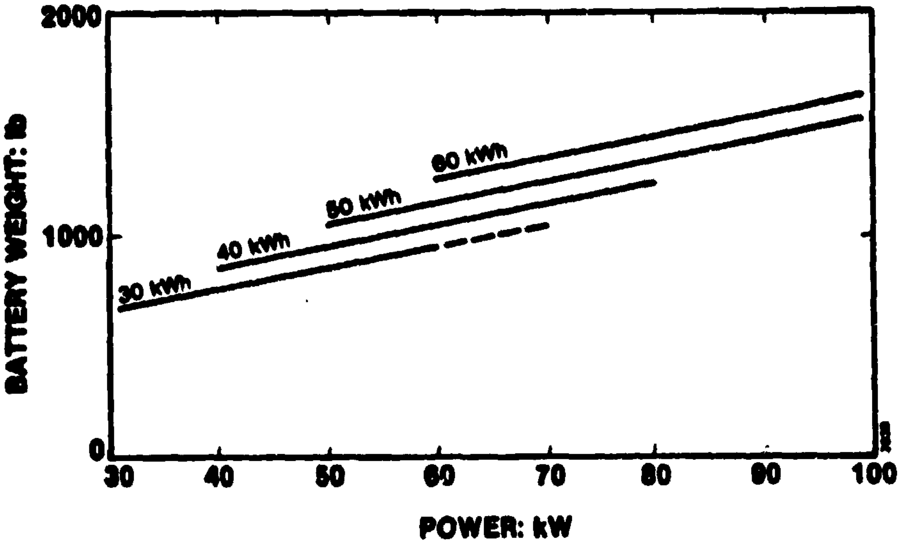

Figure 5. Battery Power, Energy, and Weight Relationship

Figure 6 shows the relationship between battery power, energy, and selling price. This figure shows the sensitivity of battery selling price to battery power level and the relative insensitivity of price to battery energy. A 30-kW, 30-kWh battery would sell for \$2,500 and a 60-kW, 30-kWh battery would sell for \$3,750, a 50% increase in selling price. Conversely an increase in battery energy increases the selling price of higher power batteries at a rate of only ~\$10/kWh.

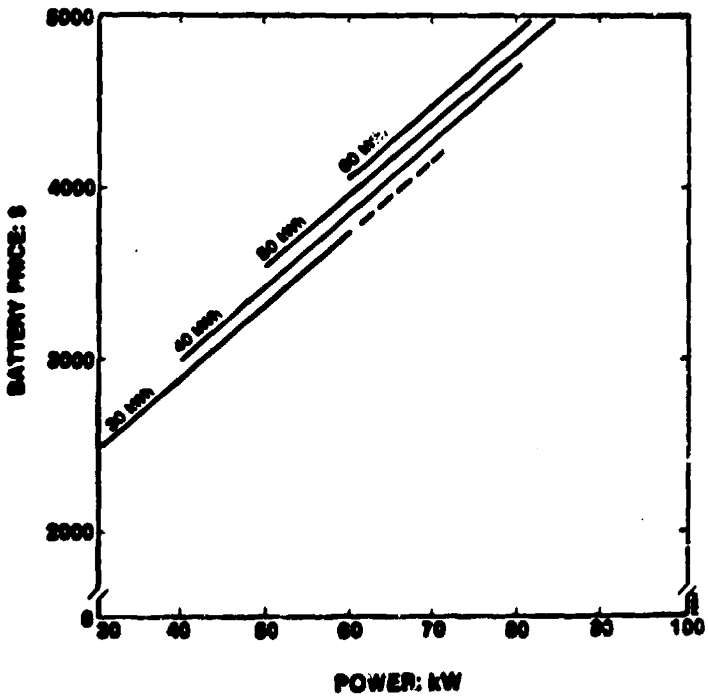

Figure 6. Battery Power, Energy, and Selling Price Relationship

RESPONSE TO JPL GUIDELINES

This section of the report summarizes the results of the assessment conducted in accordance with the "Guideline For Contractor Response." The order of presentation is consistent with the format of the guideline document.

Battery Technological Projections

Zinc-chloride battery performance and cost projections were made for four specific vehicle batteries. The four batteries and their delivered energy and power requirements are as follows:

Commuter Vehicle Battery -- 12 kWh, 25 kW
Hybrid Vehicle Battery -- 15 kWh, 50 kW
General Purpose EV or Commercial Van Battery -- 25 kWh, 60 kW
Full Performance EV Battery -- 50 kWh, 50 kW

The technological projections for these four batteries as well as other zinc-chloride batteries in this report are limited to batteries which could be demonstrated in prototype form in the early 1990s. The projections are for one-year old batteries operating in 70°F ambient air.

Performance Modeling

A battery model was used to project performance and weight of zinc-chloride batteries for various battery energy storage and power requirements. The basic design parameters for this model are as follows:

- o Delivered capacity of 160 mAh/cm^2 of electrode surface
- o Delivered energy of 300 mW/cm^2 at 30-sec peak power
- o Chlorine storage density of 0.27 g/cc of store volume

Projected discharge characteristics of the four specified vehicle batteries are compared in Tables 1 and 2. These projected characteristics are compared with a 43-kWh, 40-kW battery that reflects the present state-of-the-art of zinc-chloride battery technology.

Table 1 compares the specific energy (Wh/kg) at various discharge rates for the subject batteries.

Table 1

SPECIFIC ENERGY (Wh/kg) FOR VARIOUS DISCHARGE RATES

Battery Design	Discharge Rate (W/kg) 20	60	80	100	30 Sec Peak (W/kg)
1. Present	67	51			63
2. Commuter	66	60	58	55	133
3. Hybrid	50	47	46	44	162
4. Gen. Purpose EV or Van	65	61	58	56	150
5. Full Performance	110	100	93	85	108

Table 2 compares the 30-second peak power capability at various state-of-charge percentages. These values reflect the relatively flat voltage profile of the zinc-chloride battery throughout the entire battery discharge.

Table 2

30-SECOND PEAK SPECIFIC POWER (W/kg) AT VARIOUS PERCENT STATE-OF-CHARGE AS DEFINED BY A STANDARD C/4 RATE

Battery Design	80	50	30	10
	% SOC			
1. Present	62	61	61	60
2. Commuter	132	130	128	127
3. Hybrid	160	158	156	154
4. Gen. Purpose EV or Van	149	147	145	144
5. Full Performance	107	105	104	103

<u>Cost Projections</u>

Estimates of battery selling price of the four specified vehicle batteries and a present state-of-the-art 43-kWh, 40-kW battery are compared in Table 3. The estimates are for batteries in mature production of 100,000 units per year.

Table 3

SELLING PRICE OF VEHICLE BATTERIES

Battery Design	$/Battery
1. Present	4,000*
2. Commuter	2,026
3. Hybrid	3,154
4. Gen. Purpose EV or Van	3,684
5. Full Performance	3,525

*Engineered for manufacturing

Technical Support for Projections

Research and development in several areas to advance the state-of-the-art of zinc-chloride batteries is a continuing effort at EDA. Development of the following components, systems, and processes is expected to lead to the achievement of the battery performance and price projected for the early 1990s.

Store (hydrate storage process): Increasing the chlorine hydrate storage density significantly impacts on battery weight and volume as well as reduces cost. Using straight filtration, chlorine packing densities of 0.20 g/cc of store volume are presently achieved in 40-kWh size stores and densities up to 0.25 g/cc have been achieved in 20-kWh size stores. Chlorine storage densities in the range of 0.30-0.40 g/cc have been demonstrated with hydrate pellets.

Cell Electrodes: Lower cost graphite electrodes and improved activation processes have a direct effect on battery performance, weight, volume, and cost.

Unit Cell: Development of unit cell designs offer promise of reduced cost through reduced component parts, fabrication, and assembly. Unit cell design development also has promise of significant improvements in stack performance and efficiency.

Materials of Construction: Improvement of materials promises reduced fabrication costs and reduced maintenance costs due to a reduction of contaminants in the electrolyte.

Battery System: Battery system development aimed at system and component simplification promises reduced costs and improved reliability.

Energy Balance

To quantify sources of energy use such as self discharge, parasitic losses, etc., under vehicle driving conditions, a total energy balance was performed for a zinc-chloride battery through an entire driving cycle. The cycle utilized for this energy balance is the simplified 24-hour driving pattern requested in the "Guidelines for Contractor Response" furnished by JPL. This driving pattern, which certainly cannot be considered as a typical EV driving cycle, is illustrated in Figure 7. The driving portion of this pattern (designated driving cycle 3) was proposed by JPL to the EHV Battery Task Force as a greatly simplified version of the Federal Urban Driving Schedule to be used for life-cycle testing. This driving cycle is detailed in Table 4.

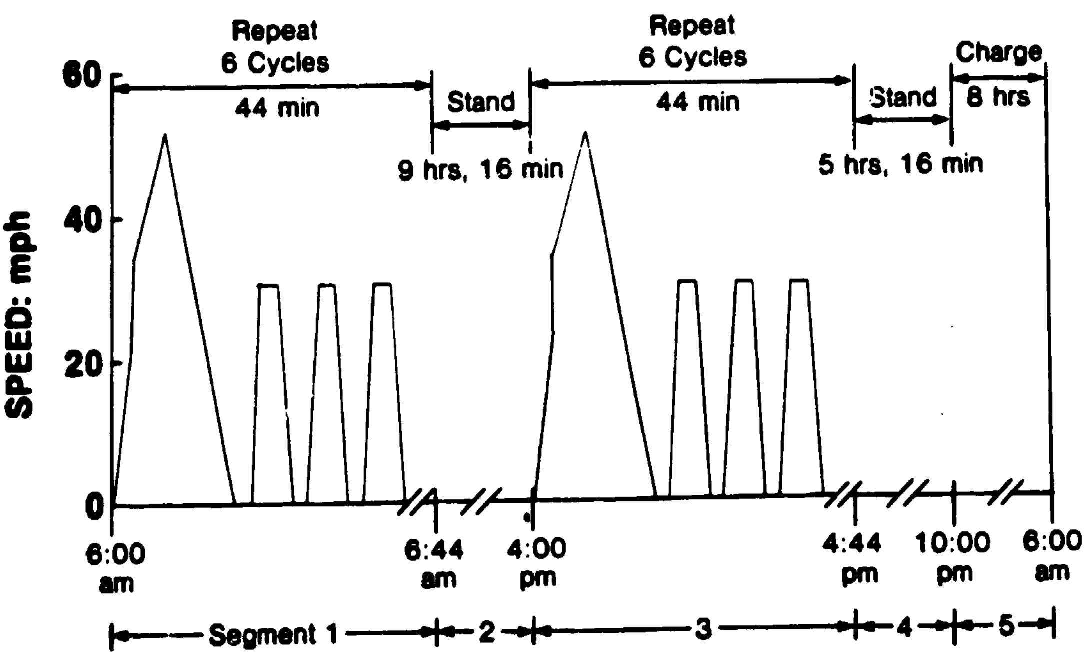

Figure 7. Simplified 24-Hour Driving Pattern

C-2

Table 4

DETAILED DRIVING CYCLE 3

Cycle Segment No.	Time (s)	Type*	Energy Consumed (W-s/kg)	Average Power (W/kg)
1	0-26	A	298	12
	26-30	A	358	89
	30-74	A	1428	33
	74-76	A	94	47
	76-171	D	-265	-3
2	171-196	S	0	0
	196-211	A	497	33
	211-236	C	175	7
	236-251	D	-155	-10
3	251-276	S	0	0
	276-291	A	497	33
	291-316	C	175	7
	316-331	D	-155	-10
4	331-356	S	0	0
	356-371	A	497	33
	371-396	C	175	7
	396-411	D	-155	-10
	411-436	S	0	0

*A - acceleration
C - cruise
D - deceleration
S - stand

All calculations of the total energy balance were based on the ETV-1 vehicle battery weight of 488 kg.

The total energy balance was calculated for a zinc-chloride battery design based on performance levels projected in the early 1990s. This battery has a design 30-second peak power of 50 kW, a delivered energy of 52.7 kWh at a C/4 discharge rate, and a total weight of 472 kg. Although the total energy consumed in the 24-hour driving pattern is small compared to the energy storage capacity of this battery, this size battery was chosen to approach the weight of the ETC-1 vehicle battery (488 kg) used as the calculation base.

The estimates of in use energy consumption and the energy balance of the zinc-chloride battery for the 24-hour driving pattern are shown in Table 5.

Table 5

ESTIMATES OF IN-USE ENERGY CONSUMPTION (Wh) FOR 24-HOUR DRIVING PATTERN

Parameters	Segments 1	2	3	4	5
Start-up/ Shut-down	0	0	0	0	0
Self-discharge & Shunt Current	931	135	931	135	1307
Parasitics	157	204	157	116	464
Thermal Loss	0	0	0	0	0
Net Heat Rejection	924	320	924	237	2869

Total Energy Delivered (segments 1 & 3) = 5,634 Wh
Total Energy Input on Charge (segment 5) = 11,660 Wh
System Discharge Efficiency = 64.4%
System Charge Efficiency = 75.0%
Overall Round-Trip Efficiency = 48.3%

Net battery ampere hours and watt hours delivered and ampere hour and watt hour losses for the discharge segments (segments 1 and 3) of the 24-hour driving pattern were calculated by a detailed analyses of the four modes of operation in the segments, i.e., acceleration, cruise, deceleration, and stand. The 8-hour charge segment (segment 5) of the 24-hour pattern was calculated as a 0.5-hour period for store electrolyte cool down to hydrate formation temperatures and a 7.5-hour battery charge. The net heat rejected in each segment includes all parasitic, shunt, self discharge, thermodynamic heat, heat of hydrate formation (charge) or decomposition (discharge), and voltaic losses. Regenerative braking is assumed during deceleration and the associated voltaic losses are included. The total energy input on charge, the system charge efficiency, and the overall round-trip efficiency include the energy input of the refrigeration unit for the 8-hour duration of segment 5.

Because the consumed energy in segments 1 through 4 is only a fraction of the storage capacity of the zinc-chloride battery in this weight class, the values in the charge segment (segment 5) are normalized by this fraction to permit proper battery evaluation. With this zinc-chloride battery, the driving pattern could be repeated approximately seven times on a single charge. Due to the fact that the zinc-chloride battery has no start-up or shut-down losses and operates at near ambient with no thermal losses, these parameters in Table 5 are designated as such.

It is assumed that the 24-hour driving pattern requested in the Guideline is for battery evaluation purposes only. EDA does not consider this pattern to be representative of any urban driving cycle and is considered to be a worst-case duty cycle for flowing electrolyte batteries because of the many active stand requirements. The round-trip efficiency for this driving pattern is 48% as compared to a round-trip efficiency of ~60% for a standard C/4 discharge cycle. The efficiency for a truly representative driving pattern would be somewhere between these values; more likely in the range of over 50% and under 60%.

Life Considerations

Due to the cost and time required for cycle life testing with vehicle batteries, life cycle test data are limited. Most of the data available are for zinc-chloride cells and batteries that are indicative of but not identical to vehicular batteries. EDA has operated a zinc-chloride battery-powered vehicle approximately 25,000 equivalent miles with varying states of charge. The number of cycles on this vehicle battery is 202 to date. Modules in load-leveling batteries -- which incorporate the same basic cell design and materials -- have performed through the equivalent of 1,724 cycles. Although not part of any formal life-cycle test program, experimental zinc-chloride cells have operated over more than 600 cycles. Data collected from these cells and batteries indicate that the gradual oxidation of the porous-graphite chlorine electrodes will establish the useful life of zinc-chloride electric-vehicle batteries. Carbon dioxide formation rates suggest that the chlorine electrodes will experience only a 10% reduction in weight after 150,000 vehicle miles.

These data are summarized in Table 6.

Other Operational Characteristics

Zinc-chloride batteries offer the capability of over-charge and over-discharge without producing any serious safety hazards or permanent damage to the batteries. The depletion of zinc ions during overcharge results in an increased H_2 formation rate at the zinc electrodes. This is handled by recombining the H_2 with Cl_2 in the gas phase using the recombination reactor. Due to the fact that excess chloride ions are present -- in the form of supporting salts --, the major anodic reaction during over-charge continues to be the oxidation of chloride ions to chlorine. This chlorine is then available for recombination with the H_2 and return to the electrolyte as HCl.

Table 6

PRESENT STATUS CYCLE LIFE

	Cycle Life	Depth of Discharge	Life-limiting Mechanisms
Cells			
	>600*	Varied	CO_2 formation rates indicate 10% wt. loss in chlorine electrodes at 150,000 vehicle miles.
Modules			
	>1700	100%	Chlorine-electrode loss due to extensive accidental overcharges.
Batteries			
Vehicle	200	100%	Both units remain operational.
Load-Leveling	170	100%	

*Cells employed for developmental purposes and were not part of a formal life test program.

Upon overdischarge zinc-chloride cells revert to chlorine-chlorine cells due to the excess inventory of chlorine in the system. Typical 50-kWh zinc-chloride batteries contain a minimum inventory of 0.6 kg of excess chlorine as chlorine dissolved in the battery electrolyte and 1 atm absolute chlorine pressure in the gas phase of the battery. Upon depletion of metallic zinc from the dense-graphite zinc-electrode substrates, the electrode reaction becomes the anodic formation of chlorine from available chloride ions. The corresponding cathodic reduction of dissolved chlorine to chloride ions continues at the porous-graphite chlorine-electrode substrates of a reversed (overdischarged) cell.

Cell balancing in a zinc-chloride battery is accomplished by completely stripping zinc from all the cells in the battery, i.e., cell balancing is accomplished by periodic complete discharge. Zinc-electrode shape changes, associated with nonuniform shunt current and primary current distributions during partial depth-of-discharge operation, suggest the desirability of conducting periodic cell balancing operations after every 5,600 Ah of charge or the equivalent of every 10 complete charge/discharge cycles.

Maintenance operations on commercial zinc-chloride batteries will be conducted primarily to ensure the proper operation of mechanical and electrical components in the system. Valve seats, pump bearings and wear plates, etc., may require replacement on an annual or biannual basis. Electronic components -- pressure transducers, temperature sensors, etc., -- could require annual recalibration and occasional replacement. Inerts-gas rejection will be handled automatically at complete discharge and adjustments to the electrolyte pH will be required on about a biannual basis.

Zinc-chloride batteries are designed to allow for the replacement or refurbishment of failed mechanical and electrical components or subsystems. The battery stack can, in accidental contamination situations, be refurbished by draining and chemical cleaning. Although present stack designs do not allow for easy electrode replacement, it is possible to replace unit cells and thereby refurbish a battery stack. Unit cell replacement offers cost savings over stack replacement for about two-thirds the life of the battery. Beyond the equivalent of 80,000 vehicle miles on the battery the cost of cell replacement may not be economically justified.

Packaging Flexibility

Table 7 compares the projected volumes of the four specified vehicle batteries and a present state-of-the-art 43-kWh, 40-kW battery.

Table 7

VOLUME OF VEHICLE BATTERIES

Battery Design	Volume (liters)
1. Present	464
2. Commuter	144
3. Hybrid	253
4. Gen. Purpose EV or Van	325
5. Full Performance	366

A cell stack is a number of unit cells fabricated in series in bipolar fashion. The present minimum dimensions of a unit cell are 2.9 inches in length, 9.7 inches in width, and 5.5 inches in height including supply and return manifolds. A cell stack contains anywhere from 20 to 40 cells depending on the power and packaging requirements. Therefore the minimum stack dimensions are height 5.5", width 9.7", and length 2.9" x number of cells.

The main battery components are the stacks, sump, and store. From an operational standpoint these components can be packaged anywhere in the vehicle that is practicable. The only special consideration as to their relative placement is weight distribution in the vehicle.

CONCLUSIONS

The results of this assessment indicate that zinc-chloride batteries can provide a cost-effective power source (∿70 $/kWh) for electric vehicles which have a power-to-energy ratio of approximately one. Although life-cycle costs are not specifically addressed in the report guidelines, they will be very low for zinc-chloride batteries because of the low capital cost, low-maintenance, and long-life features of this system.

With regards to efficiency, zinc-chloride batteries will operate with round-trip efficiencies in the range of 50-60% depending upon the duty cycle. The projected efficiency for the duty cycle specified in the guidelines is 48%. This cycle is unduly severe on flow-type batteries -- due to the large number of active stands involved -- and does not appear to be representative of an urban driving cycle. The projected overall efficiency for the same battery on a simple charge/discharge (at the C/4 rate) cycle is approximately 60%. These two types of duty cycles establish the extremes and operating efficiencies on typical driving cycles will likely be in the range of 53-57%.

In the areas of specific energy and specific power, zinc-chloride batteries with power-to-energy ratios of approximately one will offer values of at least 100 Wh/kg and 100 W/kg, respectively. It seems very logical that users of this type of battery, where energy can be added for a minimum penalty -- only 10 lb/kWh added weight and only 10 $/kWh added selling price --, will choose the full energy capability. The extra energy can be used for creature conveniences and/or eliminate the need to recharge a route-type vehicle on a daily basis.

APPENDIX E

IRON-AIR BATTERY DESIGN FOR THE JET PROPULSION LABORATORY

84-9D12-JPBAT-R1

IRON-AIR BATTERY DESIGN ANALYSIS FOR THE JET PROPULSION LABORATORY

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February 9, 1984

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MATERIALS SCIENCE DIVISION

Report 84-9D12-JPBAT-R1 Contract Required Document

IRON-AIR BATTERY DESIGN ANALYSIS FOR THE JET PROPULSION LABORATORY

by

D. Zuckerbrod and E. S. Buzzelli

Abstract

The iron-air battery system was modeled mathematically to predict performance, peak power, cost and the size of batteries designed for various specific electric vehicle missions. Near term (late 1980's) and advanced technology (early 1990's) performance cases were considered for commuter, hybrid, van and full performance type electric vehicles. Technical support was given for projections and consideration was given to known system losses. Boundary conditions were given for battery performance indicating design flexibility. The results of this modeling effort indicate that the iron-air couple could meet the established goals for each mission in a low cost battery system.

1. Summary

The iron-air battery system was modeled mathematically to obtain estimates of battery performance, cost, weight and size for various missions using individual electrode performance characteristics based on available data and conservative projections. Mission specifications, given in terms of energy and power, and their respective battery characteristics are summarized in Table 1-1 for the near term case (late 1980's) and in Table 1-2 for the advanced technology case (early 1990's). Details of the calculations and of the model used to calculate the derived quantities expressed in this report are available upon request. They were not included as they were beyond the scope of this work.

Table 1-1. Summary of Near Term Battery Characteristics.

Mission	Energy[1] (kWh)	Power[1] (kW)	Sp.Ener.[2] (Wh/kg)	Pk.Power[3] (W/kg)	Cost ($/bat.)	Volume (l)
Commuter	12	25	98	203	880	102
Hybrid	15	50	72	240	1524	208
EV or Van	25	60	90	215	1831	279
Full Perf	50	50	139	139	1744	260

Table 1-2. Summary of Advanced Technology Battery Characteristics.

Mission	Energy[1] (kWh)	Power[1] (kW)	Sp.Ener.[2] (Wh/kg)	Pk.Power[3] (W/kg)	Cost ($/bat.)	Volume (l)
Commuter	12	25	126	262	636	81
Hybrid	15	50	93	309	1031	147
EV or Van	25	60	115	277	1230	187
Full Perf	50	50	181	181	1197	204

1. requirement defined in "Guidelines for Contractor Response"
2. using "Cycle 3" driving cycle
3. from 100% to 20% SOC

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The results of the modeling effort clearly indicate that the iron-air battery system could meet the goals for each mission. Battery cost, weight and size all fall within the range judged necessary for an electric vehicle propulsion battery.

2. Introduction

The iron-air cell, consisting of a porous sintered iron electrode coupled to a carbon-based bifunctional air electrode, has the characteristics necessary for the development and demonstration of a successful battery system for electric vehicle propulsion. The cell reaction during discharge is as follows:

$$Fe + 2\,OH^- \longrightarrow Fe(OH)_2 + 2\,e^- \quad \text{(anode)}$$

$$1/2\,O_2 + H_2O + 2\,e^- \longrightarrow 2\,OH^- \quad \text{(cathode)}$$

$$Fe + H_2O + 1/2\,O_2 \longrightarrow Fe(OH)_2 \qquad E^\circ = 1.283\ V$$

This system has many advantages in terms of battery design and commercial applicability. The most obvious advantage is the inexhaustability and therefore the invariance of the positive electrode. Oxygen is supplied from ambient air (scrubbed free of CO_2) during discharge and returned to it during charge. This, in part, helps to maintain the flat discharge curve (voltage vs. state of charge) exhibited by iron-air cells. The air electrode can neither be overcharged nor overdischarged with respect to cathode capacity and utilization thus making cell balancing unnecessary and simplifying equalization. The power and energy of a cell can be varied almost independently by varying the area of the cell (power) and the thickness of the iron electrode (energy). This allows great design flexibility and the tailoring of the battery to a specific mission requirement. This design flexibility is not available in other secondary battery systems.

The materials used in iron-air cells are low in cost and are available in an almost inexhaustable supply. The air electrode is catalyzed with a low loading of silver (1-2.5 mg/cm^2) This low level of peroxide elimination catalyst represents only a small part of the estimated cost of the electrode(less than 25% @ $9/oz.).

Finally, electrode life in excess of 500 cycles for both the iron and air electrodes has been demonstrated in half-cell tests. Full-cells have been tested

with lifetimes in excess of 100 cycles but these do not reflect state-of-the-art air electrodes which have since been improved considerably.

The present status of the Iron-Air Battery Development Program is as follows:

- The iron electrode has met the near term goal of 0.4 Ah/g for greater than 500 cycles.
- The air electrode is undergoing continued development and has improved in performance and reproducibility. Lifetime in excess of 500 cycles has been demonstrated.
- Iron-air cell testing and development was terminated in 1980 at the request of the sponsor in order to focus on advancing the cycle life characteristics of the air electrode.

Estimates of near term cell performance used in this study were based on previous cell testing with the results adjusted to reflect subsequent improvements in the air electrode.

3. The Model

The goal of this work was to estimate the performance, weight and cost of an iron-air battery for electric vehicle propulsion. Such a battery, with the desirable characteristics reported herein, has not been built. A mathematical model was employed to generate these values from existing half-cell and full-cell data. Two scenarios were considered, a near term (late 1980's) case and an advanced (early 1990's) case.

3.1 Assumptions

The driving cycle assumed for battery discharge was "Cycle 3", appended at the end of the "Guidelines for Contractor Response." Regenerative braking was disregarded as it was only a small factor in the design of the battery.

Cell polarization curves are shown in Figure 3-1. They include resistive losses in the electrolyte. For the purpose of the model, the curves were considered to be linear and a least squares fit was made through the input polarization data. The slope and intercept so obtained were used to calculate the characteristics of the battery. Physical assumptions used to calculate cell performance are given in Table 3-1. The low estimate for auxilliary weight was derived in part from the minimal cell casing required. The major faces of the cell container are the air electrodes, whose weight is included as the electrode itself.

The energy requirements for parasitic losses were defined not to exceed 5% of the battery energy based on the results of an earlier system study*. The power penalty for this steady load is minimal and was ignored. The parasitics need not operate when the vehicle is shut down. The system consists of a blower for cell air, an electrolyte circulation pump, a heat exchanger, a carbon

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*B. G. Demczyk, R. E. Grimble, "Thermal Management of the Iron-Air Battery System," *ECS Extended Abstracts*, 81-2 (1981)

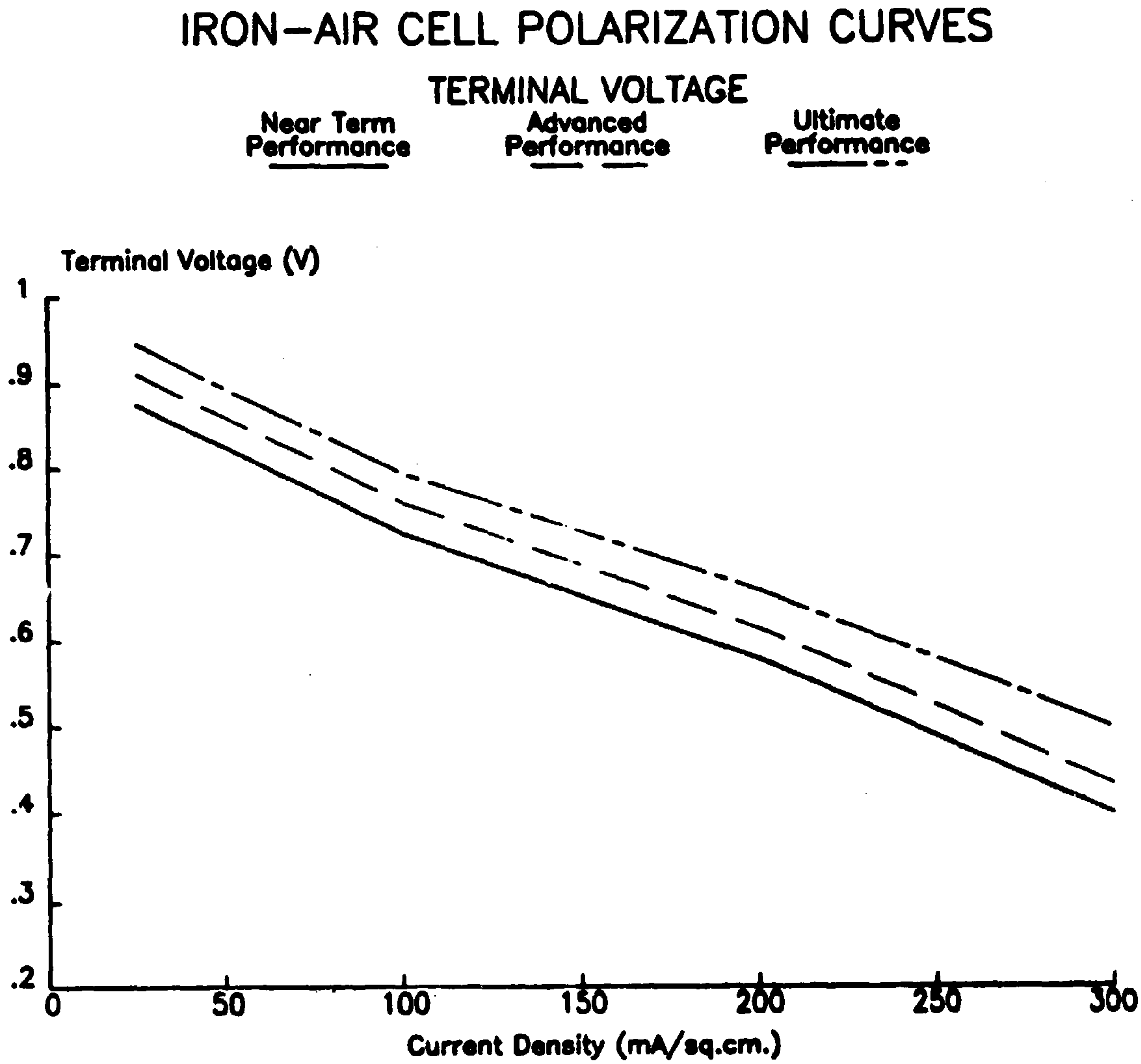


Figure 3-1. Iron-Air Cell Polarization Curve.

dioxide scrubber, and a packed-bed humidifier-dehumidifier. The cost estimate of $200 used for peripherals, shown in Table 3-2 with the iron and air electrode cost assumptions, appears reasonable at this stage of development of the iron-air battery system. Further development of real systems in a future hardware development program will provide more realistic costs for the peripherals.

Table 3-1. Physical Assumptions for the Battery Model.

Parameter	Near Term	Advanced	
Air Electrode Density	1.14	1.14	g/cm^3
Air Gap	0.1	0.1	cm
Air Electrode Weight	0.2	0.15	g/cm^2
Iron Electrode Density	1.68	1.68	g/cm^3
Iron Electrode Capacity	0.4	0.5	Ah/g
Electrolyte Density	1.23	1.23	g/cm^3
Electrolyte Conductivity	0.48	0.48	$ohm^{-1}cm^{-1}$
Electrolyte Gap	0.1	0.1	cm
Theoretical Potential	1.283	1.283	V
Charging Potential	1.53	1.5	V
Current Efficiency (charge)	90	95	%
Auxilliary Weight	10	10	%
Auxilliary Volume	15	15	%
Parasitics	5	5	% Energy

Table 3-2. Cost Assumptions.

Component	Near Term	Advanced	
Iron Electrode	$2.00	2.00	$/kg
Air Electrode	30.00	20.00	$\$/m^2$
Peripherals	200.00	200.00	

3.2 Calculations

The calculation of battery performance, weight and cost consisted of five parts:

1. Determination of the slope and intercept of a least squares fit of the cell polarization curve and calculation of peak power per unit area

2. Sizing the cell area to meet peak power requirements

3. Sizing the iron electrode thickness to meet energy requirements (range

to 0% SOC with some performance degradation expected from 20% to 0% SOC)

4. Iteration to converge at the desired energy with the driving cycle specified in W/kg of battery

5. Calculation of desired parameters using the battery designed in Step 4

The battery energy was increased to account for parasitic losses. Auxilliary volume and weight were factored in as part of Step 4. The calculations were performed using a "spreadsheet" program for a desktop computer.

4. Results and Discussion

4.1 Performance Modeling

The results of the performance modeling calculations are given in Table 4-1 for the near term battery performance and in Table 4-2 for the advanced performance using the assumptions given in Table 3-1.

Table 4-1. Near Term Battery Performance.
Specific Energy (Wh/kg) versus Discharge Rate (Specific Power)

Bat.Design	20W/kg	60W/kg	80W/kg	100W/kg	200W/kg
Commuter	104	98	95	92	60
Hybrid	77	73	71	69	55
EV or Van	96	91	88	85	62
Full Perf.	151	137	129	120	*

* exceeds peak power

Table 4-2. Advanced Battery Performance.
Specific Energy (Wh/kg) versus Discharge Rate (Specific Power)

Bat.Design	20W/kg	60W/kg	80W/kg	100W/kg	200W/kg
Commuter	134	128	125	122	101
Hybrid	98	94	93	91	80
EV or Van	123	118	115	113	95
Full Perf.	195	182	175	167	*

* exceeds peak power

The flat discharge curve (potential vs. state of charge) for iron

electrodes and the invariance of the air electrodes indicate constant peak power independent of state of charge down to 20% SOC. After this, performance would be expected to degrade and polarization data to become erratic due to the characteristics of the iron electrodes and expected spread in the electrode capacities. The resistance of the iron electrode is essentially constant for the $Fe(OH)_2$ reaction, and as a result, the power characteristics for the cell/battery are constant during a discharge. This is unique to the iron-air system as compared to other secondary systems where impedance increases with depth of discharge. Peak power, which is constant from 100% to 20% SOC is given for the near term and advanced batteries in Table 4-3.

Table 4-3. Specific Peak Power (W/kg from 100% to 20% SOC).

Battery Design	Near Term	Advanced
Commuter	203	262
Hybrid	240	309
EV or Van	215	277
Full Performance	139	181

4.2 Cost Projections

Using the assumptions shown in Table 3-2 and the iron weight and air electrode area requirements calculated by the model, the battery costs are projected in Table 4-4.

Table 4-4. Battery Cost Projections.

Battery Design	Near Term	Advanced
Commuter	$889	636
Hybrid	1524	1031
EV or Van	1831	1230
Full Performance	1744	1197

It must be noted that at the present stage of cell development, a detailed cost

study may not be meaningful. The assumed values appear to be reasonable in light of materials cost and the cost of related processes used in other Westinghouse products. A justification of the costs, is based on a 1980 manufacturing cost estimate completed at the request of Lawrence Livermore National Labs. The present electrodes may, in fact, provide a cost reduction to the 1980 estimate of $40/kWh.

4.3 Technical Support for Projections

Technical support for the projections made in this report is given in Table 4-5.

4.4 Energy Balance

The iron-air battery is an ambient temperature and pressure device. Therefore, start-up and shut-down losses are not encountered as they would be in high temperature fuel cells, molten salt or metal-halogen systems. Waste heat upon use will be sufficient to warm the battery to its operating temperature (35-45°C). Similarly, thermal loss is not seen as a problem.

The self discharge of iron-air cells has never been studied in detail at Westinghouse. However, it is felt that this is not a major problem. The air electrode can not self discharge in the usual sense (by evolving O_2 as nickel electrodes do). While mono-functional air electrodes tend to fail rapidly at open-circuit conditions due to carbon and catalyst oxidation (another sort of self discharge), the Westinghouse air electrode is fully bi-functional and thus is engineered to withstand the high potentials associated with oxygen evolution. The lower potentials associated with open circuit conditions do not appreciably damage the electrode. The iron electrode, however, may self discharge by evolving hydrogen. This can be controlled by minimizing impurities in the iron and the electrolyte to minimize the number of low overvoltage sites for hydrogen evolution. It is estimated, based on half cell test results, that the self discharge occurs at the rate of about 1% of the battery capacity (iron electrode capacity) per day, but there is no firm evidence here other than the half-cell observation. Shunt currents can not be estimated at this stage of battery developm[illegible], as

Table 4-5. Technical Support for Projections.

Component	Present Status	Design Change	Performance Change	Cost Change	Comments
Air Electrode					
• Current Collector	Ni-fiber mat	Ni-plated steel wool mat	lower charge voltage	lower	extensive (W) experience
• Active Material	Teflon™ bound carbon + catalyst	non-fluorinated binder	lower weight shorter break-in	much lower	new materials available
		improved catalyst	higher discharge voltage	slight	study by CWRU
• Hydrophobic material	Teflon™ bound carbon	Hostaflon™ bound carbon	longer life less flooding	slight	cationic surfactant neutralized in base
Iron Electrode					
• Current Collector	Ni-EXMET™	improved configuration and tabbing	better utilization lower resistance	slight	tab welds show high resistance
• Active Material	sintered porous iron	improved purity	better charge efficiency	slight increase	
Separator					minimal separator needed only to prevent electronic shorts
Other components					will be designed as needed

experience with other than single cells is extremely limited. Development of the full battery will surely attempt to minimize these shunt current losses.

Peripherals giving rise to parasitic losses during battery operation are an electrolyte pump, an air blower, and a packed-bed humidifier-dehumidifier. These need only operate when the vehicle is operating and perhaps shortly thereafter to avoid high temperatures after shut-down. A detailed thermal study of the iron-air battery system (1980) indicated that parasitic losses would not exceed 5% of the total battery energy for a nominal 20-40 kWh battery system.

The energy efficiency of the iron-air battery was resolved into the charge efficiency and discharge efficiency with the product of the two being the overall energy efficiency of the battery. The charge efficiency assumed a charge potential independent of rate because the rate will vary only slightly for an over-night charge. The discharge efficiency assumed the driving cycle used for the performance modeling. Regenerative braking was ignored as only an incrimental benefit, but can be accepted by the battery.

The energy balance information is summarized in Table 4-6.

Table 4-6. Estimates of In-Use Energy Comsuption.

Parameter	Segments				
	1	2	3	4	5
Self Discharge*	-	20W	-	20W	
Parasitics*	1000W	-	1000W	-	100W
Energy Efficiency**	65(68)%	-	65(68)%	-	76(81)%

Segments
1. Morning driving cycle
2. Mid-day stand
3. Afternoon driving cycle
4. Evening stand
5. Overnight recharge

*Energy Consumption: Power, continuous over segment
**Energy Efficiency: Near term (Advanced Technology)%

4.5 Life Considerations

Iron electrodes and air electrodes have demonstrated lives of over 500 cycles in half cell tests. Actual iron electrodes have exceeded well over 1000 cycles with a somewhat different structure and lower electrode utilization. Full cells have demonstrated life of over 100 cycles with older, less stable air electrodes (pre 1980). The life limiting mechanism for air electrodes is the loss of structural integrity and hydrophobicity due to the corrosion of carbon and attack of the Teflon binder. This, in turn, limits the life of the cell. Cell life is not sensitive to depth of discharge (at least down to 0% SOC and perhaps further). Life test data does not exist for modules and batteries.

The life for an iron-air battery is presently projected to be greater than 500 cycles. No relationship between the ratio of power to energy and cycle life is forseen for a properly designed cell, but once again, no experimental evidence exists in the cell engineering area. An ongoing air electrode research program is aimed at improved air electrode performance, uniformity, reproducibility and life. To date, improvements in both the air electrode structure and catalysis have involved either no change or a significant reduction in cost compared with earlier, less successful designs.

The performance of the air electrode remains constant for several hundred cycles after break-in (a few cycles). The performance then begins to decay linearly for perhaps another hundred cycles. At the end of life, the electrode may fail through gross leakage of electrolyte (case rupture) or flooding, whereupon oxygen reduction is not supported and hydrogen evolution occurs if the cell is driven. After the intial cycle, the iron electrode performance is essentially unchanging for many hundreds of cycles given chemically clean operating conditions (no CO_2 or low H_2 overvoltage impurities). So degradation of power, energy and efficiency follows the decay of the air electrode performance. No estimate of the reliability of a battery module (5 cells in parallel) is available at this time as experimental data is not available. It would be expected that the iron electrode could be manufactured to within $\pm$2-3% of design capacity. The air electrode would probably be $\pm$5 mV.

4.6 Other Operational Characteristics

It is impossible to overcharge or overdischarge the air electrode. As long as electrolyte and air are available, the electrode is invariant. Iron electrodes are not damaged by overcharging. This is well known for iron-nickel batteries, which require overcharging for proper operation. Overdischarging will take the iron electrode to a "second plateau" where the Fe^{+2} is oxidized to Fe^{+3}. Thus the battery can be considered to have some emergency capacity if it were needed, albeit at very low power densities. Iron electrodes have been driven to oxygen evolution and then recharged with no apparent ill effects. Hence, the system is extremely tolerant to severe abuse in the form of extended overcharge and deep discharge well past the point of reversal, with no deleterious effects on performance or life. Individual cell balancing is never required in the iron-air battery due to the invariant air electrode. The cells are always in balance by definition. Periodic complete discharge is not required for proper cell operation. The battery is self-equalizing during charging as slight overcharging is normal and causes no damage while continuing to charge the cells of greater capacity.

Some regular maintenance is required for proper battery operation. Make-up water must be added to replace that lost to evaporation and electrolysis. The carbon dioxide scrubber will need its medium changed periodically and the electrolyte will also have to be changed at some relatively infrequent interval. Air and electrolyte filters will require cleaning and/or replacement and electrical connections may have to be inspected and cleaned. No estimate can be given for the frequency of these tasks as battery development has not yet reached a stage where estimates would be meaningful.

The low cost nature of the iron-air system will probably make battery refurbishment unnecessary with the exception of the replacement of a prematurely failed module.

4.7 Packaging Flexibility

Table 4-7 shows volumes predicted for various battery designs by the model. The values include a 15% volume penalty for auxilliary systems. The size and shape of the iron-air battery appears to be very flexible. The constraints, at

Table 4-7. Predicted Battery Volume.

Battery Design	Near Term	Advanced
Commuter	102	81 liters
Hybrid	185	147
EV or Van	236	187
Full Performance	260	204

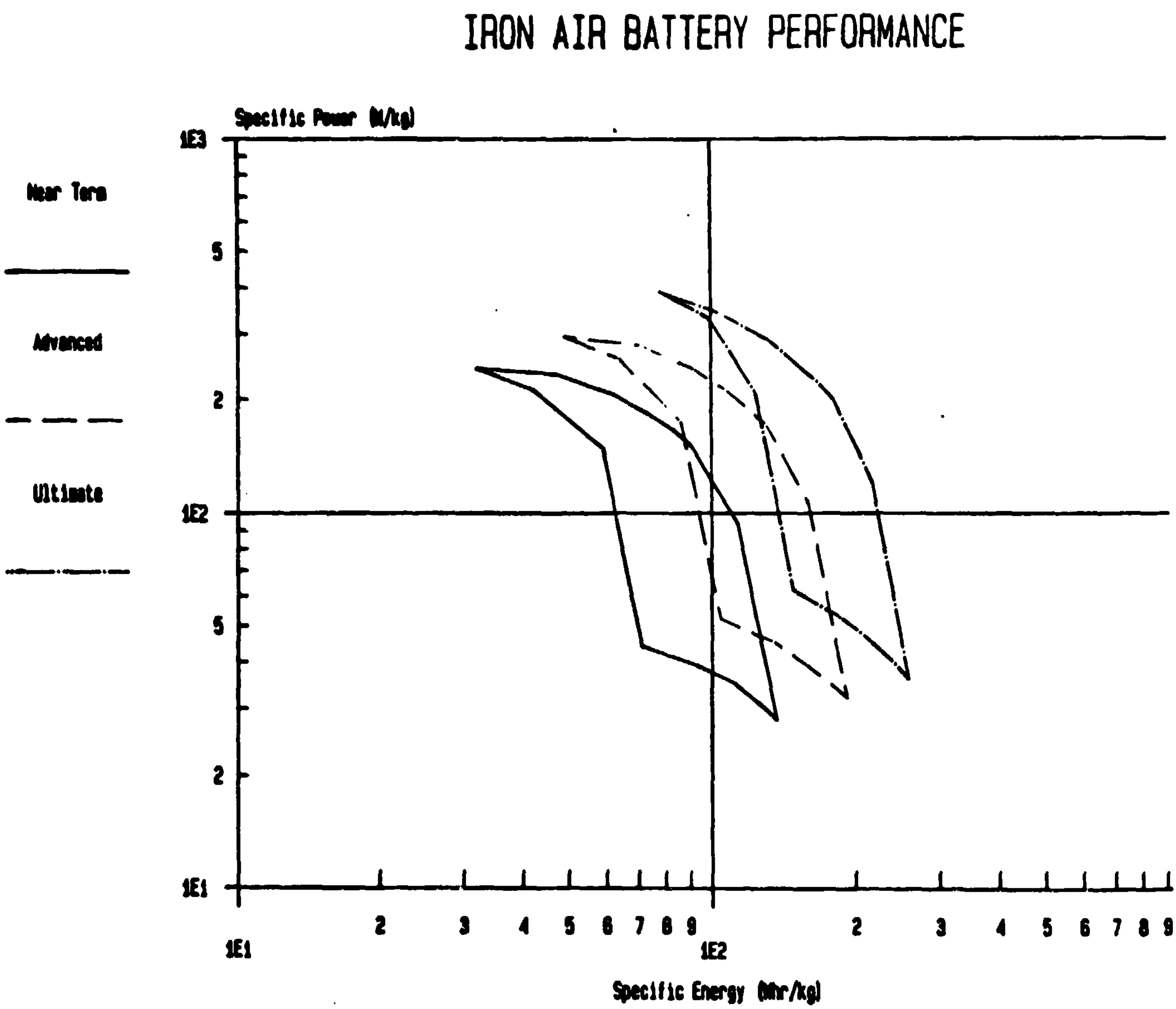
this point in time, are that edge current collection is required by the system and air must be supplied to the air electrodes. A change in electrode shape would require redesign of the current collector with a possible weight penalty for an unfavorable shape. Both horizontal and vertical cell designs are being considered. Subsystems are required to handle air flow and electrolyte circulation. While placement of subsystems at a location remote from the battery will increase system complexity and weight and volume penalties, ducts and tubing can be designed as needed for spatial considerations.

While iron-air cells show no special scaling problems, the peripherals may have minimum sizes and weights adding a penalty to the low end of the 10-50 kWh range. Design of the auxilliaries will be performed as the iron-air development program proceeds toward a prototype system demonstration objective.

5. Conclusion

The iron-air battery system using the Westinghouse bi-functional air electrode, offers performance adequate for the specified electric vehicle propulsion missions proposed in this study. The flexibility offered by the invariant air electrode allows battery power and energy to be tailored to a specific task or vehicle mission need. The batteries are fabricated from inexpensive materials in abundant supply,resulting in a low cost battery system ($20-40 $/kWh). No special problems are expected due to start-up, shut-down or maintenance procedures and there are no inherent safety problems related to this particular system. Boundary conditions for iron-air battery performance, derived from the model used, are given in Figure 5-1. Estimates of the performance of peripheral systems include considerable uncertainty due to a lack of experimental data. Further research and development effort is required on the iron-air system to provide performance and life data which can be used to evaluate and compare this system to other candidates for the various EV missions. With respect to the three important battery criteria established by possible vehicle manufacturers, safety, reliability, and life, the Iron-Air system is a strong contender for use in vehicles in the 1990's.

Figure 5-1. Boundary Conditions for Iron-Air Battery Performance.



APPENDIX F

PERFORMANCE/COST PROJECTIONS FOR LITHIUM/IRON SULFIDE BATTERIES

PERFORMANCE/COST PROJECTIONS
FOR LITHIUM/IRON SULFIDE BATTERIES

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February 1984

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I. INTRODUCTION

Research on the lithium/molten salt electrolyte system at ANL and several industrial developers has given rise to a family of electrodes containing lithium in the negative electrode and sulfur in the positive electrode. The electrode couple that has received the most attention has been Li-Al/FeS with its development carried well beyond the laboratory stage. Based upon the JPL study guideline of choosing technology that could be demonstrated in prototype form in the 1990-1992 era, the Li-Al/FeS technology rather than the potentially more energetic Li-Si/FeS_2 technology has been chosen as a basis for the performance and cost projections.

The position the Li-Al/FeS couple holds in relation to other battery couples in terms of theoretical specific energy is shown in Fig. 1. As can be calculated from the values given, Li-Al/FeS has greater than 2 1/2 times the theoretical specific energy of Pb/PbO_2. The most energetic couple in the lithium/molten salt family is Li/S and has about 15 times the theoretical specific energy of Pb/PbO_2 and about 3 1/2 times that of the Na/S couple currently under development.

Research and development work on the lithium/molten salt system is worldwide. A brief summary of ongoing work is presented in Table 1.

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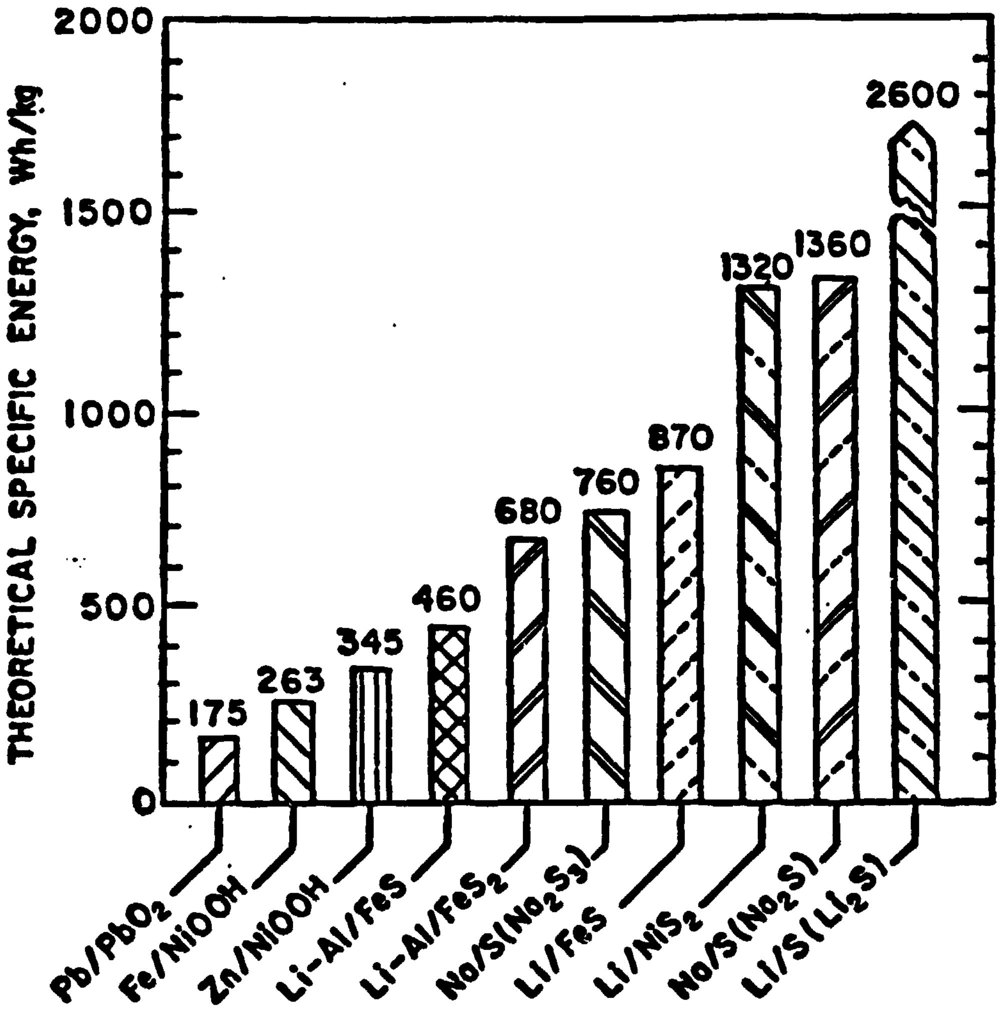


Fig. 1. Theoretical Specific Energies of Selected Battery Systems.

TABLE 1

ONGOING PROGRAMS IN Li–ALLOY/MS BATTERY DEVELOPMENT

- DOE Work at ANL
  - Research on advanced electrodes
  - Component design studies

- U.S. Army (MERADCOM)
  - Fork Lift Truck Program. Cells exceed 900 cycles

- Electric Power Research Institute (EPRI)
  - Van Battery Program
    Li–Al/FeS modules
    ANL and Gould

- U.S. Air Force
  - Satellite Battery Program. At Gould.

- International
  - Development Programs in England, Korea, Japan U.S.S.R.
  - Commercialization of Li–Al/FeS by Chemelectron (Toronto) subsidized by Canadian government

II. PERFORMANCE MODELING

Two types of battery designs were evaluated for this study. The prismatic design, presently under development at ANL and Gould for the EPRI van battery program, has excellent prospects for meeting the requirements for the commuter car and the 3/4-ton van with improved state-of-the-art Li-Al/FeS technology. The bipolar design, being tested at Gould, has the potential for significant performance improvement over the prismatic design especially in terms of power density as required by the hybrid vehicle and high energy density as required by the long-range full performance automobile.

The specific energy and peak power projections for four classes of batteries are given in Tables 2 and 3. A prismatic design using Li-Al/FeS with a MgO separator and LiCl-KCl electrolyte was chosen for the class 2 battery because (1) the requirements for the commuter car and van can be met with modest improvements in the existing technology and (2) Li-Al/FeS with a MgO separator is the system with the lowest manufacturing cost.

The bipolar battery was chosen for the full-performance automobile and the hybrid vehicle. The main distinction between the class 3 and class 4 bipolar batteries is in the use of an all lithium electrolyte (LiBr-LiCl-LiF) in place of LiCl-KCl to improve the power performance of the hybrid battery. Li-Si is added to the Li-Al alloy in the negative electrode to provide an increase in the specific energy.

A discussion of the methodology used in projecting the performance of the prismatic batteries is given in Appendix A.

A discussion of the methodology used to project the performance of a bipolar Li-Al/FeS battery is given in Appendix B.

Table 2. Specific Energy, Wh/kg

Class	Battery Designation	Battery Design	Discharge Rate (W/kg)				
			20	60	80	100	200
1	Present	Prismatic	63	50	43	35	0
2	Commuter 3/4 ton van	Prismatic	87	75	67	60	5
3	Full-Performance	Bipolar	136	115	103	90	30
4	Hybrid	Bipolar	136	115	103	90	30

Table 3. Peak Power, W/kg (30-second)

Class	Battery Designation	Battery Design	State of Charge			
			80%	50%	30%	10%
1	Present	Prismatic	150	130	100	50
2	Commuter car 3/4 ton van	Prismatic	190	170	140	90
3	Full-Performance	Bipolar	242	187	146	114
4	Hybrid[a]	Bipolar	278	215	168	131

[a]A 15% power increase over the full-performance bipolar battery is assumed due to the use of the all lithium electrolyte.

III. COST PROJECTIONS

The projected OEM price for Li-Al/FeS batteries for the commuter car, 3/4-ton van, full-performance automobile and the hybrid vehicle is given in Table 4.

The basis for the cost projections is given in Appendix C.

IV. TECHNICAL SUPPORT FOR PROJECTIONS

The principle departures from existing technology used in making the performance and cost projections were:

(1) The use of a bipolar design for the full-performance and hybrid vehicle battery as a more appropriate for the high-power and high-energy outputs that are desired. The feasibility of the bipolar design hinges to a large extent upon the development of an adequate peripheral seal. Bipolar cells have been built and tested at the British Admiralty, ANL, Gould, and Eagle-Picher. The starved-electrolyte concept being developed at Gould lends itself to bipolar designs by immobilizing the electrolyte to a significant degree. Various concepts for seals have been proposed that appear to have the potential for a successful seal. Tests of bipolar stacks at Gould have shown very promising early results.

(2) The production of all lithium-containing compounds from a feedstock of Li_2CO_3 is proposed as a method of reducing the manufacturing cost of lithium-alloy/iron sulfide batteries. This procedure requires the fabrication of cells in the discharged state, i.e., with Li_2S as the electrochemically active material in the positive electrode. Uncharged cells using a mixture Li_2S and iron powder in the positive electrode have been tested with good results at ANL.[1] The performance of the cells were about the same as for

Table 4. Projected Costs

Class	Battery Designation	Battery Design	Energy kWh	Power kW	P/E	Materials	OEM Price $/kWh	OEM Price $/Battery
1	Present	Prismatic	-	-	-	(1) Li-Al/FeS; BN Felt LiCl-KCl	-	-
						(2) Li-Al-Si/FeS; MgO LiBr-LiCl-LiF	-	-
2	Commuter 3/4 ton van	Prismatic Prismatic	12 23	24 46	2 2	Li-Al/FeS; MgO LiCl-KCl	99 99	1188 2277
3	Full-Performance	Bipolar	50	50	1	Li-Al/FeS; MgO LiCl-KCl	99	4950
4	Hybrid	Bipolar	15	50	3.3	Li-Al-Si/FeS; MgO LiBr-LiCl-LiF	115	1725

cells built in the charged state. Precautions need to be taken in uncharged cell fabrication because of the sensitivity of Li_2S to the moisture content in the atmosphere. Also, work at ANL showed that charging the cell must commence as soon as the electrolyte is molten to maximize cell lifetime. Considerable work remains in developing the uncharged cell fabrication technology to the present level of charged cell construction. Based upon the experience with uncharged cell fabrication at ANL, the prospects for the successful development of this approach for post 1990 vehicle batteries appears good.

V. ENERGY BALANCE

An energy balance for vehicle operating on the JPL modified FUD cycle was developed based upon the data supplied by JPL and assumptions given below.

Basis:

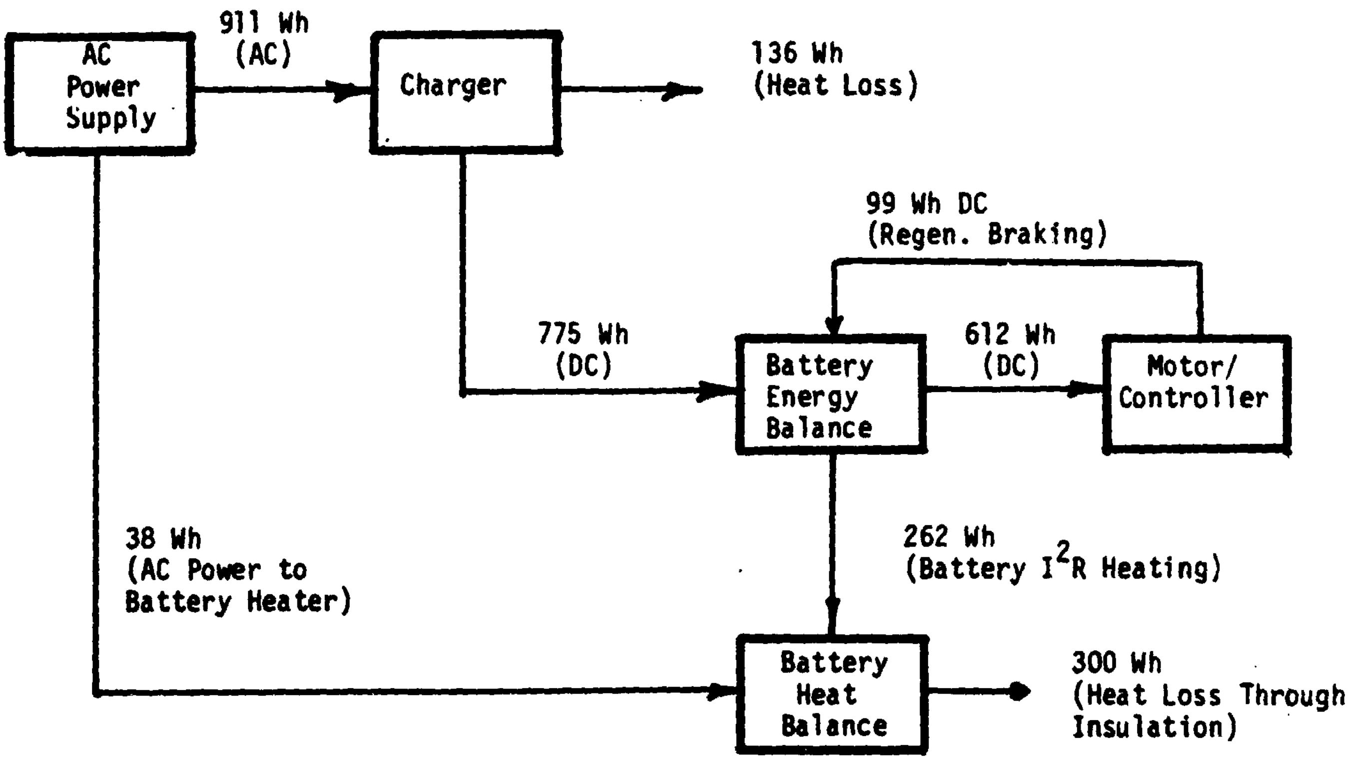
(1) Battery Weight = 488 kg
(2) Vehicle Test Weight = 1660 kg
(3) Ave Speed for Cycle 3 = 19.6 mph
(4) Time for Cycle 3 = 463/3600 = 0.121 h
(5) Cycle 3 Distance = 19.6 x .121 = 2.37 mile
(6) Distance/Day = 12 x 2.37 = 28.4 mile
(7) Battery Heat Loss at Operating Temp. = 150 W

A diagram showing the energy input/output for each major component that occurs during the performance of cycle 3 is given in Fig. 2.

Fig. 2. Energy Balance for JPL/FUD Cycle.

Basis

Cycle Segment - Cycle 3
Time/cycle 0.121 h (463 sec)
Distance/cycle 2.37 mile
Charger Efficiency 85% (DC out/AC in)
Battery Efficiency 70% (DC out/DC in)
Battery Weight 488 kg
Vehicle Test Weight 1660 kg



A summary of energy consumption and selected energy performance coefficients is given in Table 5.

Table 5. Energy Consumption

Battery Heat Loss/24 h = 150 W x 24 = 3600 Wh
I^2R heating/24 h = 262 Wh x 12 cycles = 3144 Wh
Energy Required to Maintain Temperature = 456 Wh
AC energy required = 949 Wh/2.37 mile = 400 Wh/mile
Battery DC Output = 612 Wh/2.37 mile = 258 Wh/mile
Vehicle Efficiency = 258/1.66 tonnes = 155 Wh/tonne mile
Overall Energy Efficiency = 258/400 = 0.65

The estimates of In-Use Energy Consumption is given in Table 6.

Table 6. Estimates of In-Use Energy Consumption

Parameters	Segments 1	2	3	4	5
Start-up and shut-down	None required; battery kept at constant temperature				
Self-Discharge	Negligible; Ah efficiency 98-99+%				
Shunt Current	None				
Parasitics	None				
Thermal Loss	0	24 Wh	0	14 Wh	0
Charge Eff. (DC Out/DC In)	-	-	-	-	70%

VI. LIFE CONSIDERATIONS

A. Cycle Life

Engineering-sized cells are currently achieving from 500 to >1000 cycles with prospects for achieving 1500 cycles MTTF in the next few years considered very good.

Modules of 5 to 10 cells have been tested with the lifetimes obtained generally following that expected from the life time obtained in single cell tests.(2) One module failed after only a few cycles when defects in one or more cells allowed electrolyte leakage.

The present status and projected cycle life of cells, modules, and batteries is discussed in Appendix D.

As discussed in the Appendix, a battery comprised of cells having a MTTF of 1500 cycles with a failure distribution characterized by a Weibull slope of 5 would achieve 1000 cycles with a replacement of 5 cells.

B. Life Effects

The effect of cycle life on specific energy has already been noted (Table 1, Appendix D). Capacity loss of cells has been progressively reduced from about 8%/100 cycles to present values of about 2%/100 cycles.

The resistance of the cells do not appear to change significantly with cycle life, hence the specific power is expected to be unchanged with battery life.

The coulombic efficiency of new cells range between 98-99+% with only slight decreases in coulombic efficiency occuring until cell failure, at which point the efficiency drops drastically. Failed cells, however, have been shown to contribute to battery power for part of the discharge cycle even when partially shorted.

The effect of cycle life on the thermal characteristics of the cells has not been measured. No potentially adverse effects have come to our attention.

VII. OTHER OPERATIONAL CHARACTERISTICS

A. Special Charge Requirements

The normal charge and discharge reactions in the Li-Al/FeS cell result in the formation of solid products without gaseous side-reactions, which permits the cell to be sealed and eliminates the need for electrolyte replacement. Information on the effects of overcharging and overdischarging Li-Al/FeS cells has been obtained from thermodynamic data, laboratory-scale cell experiments, full-scale cell tests, and post-test examinations of cells. The normal charge cutoff voltage (IR-included) is 1.55V and the reversible (IR-free) voltage is 1.33V. When the charge cutoff voltage is exceeded, the first significant overcharge reaction, which occurs at about 1.8 V (IR-free).

$$Fe + 2LiCl + 2Al \rightarrow FeCl_2 + 2LiAl.$$

This reaction involves (1) anodic oxidation of the iron current collector in the FeS electrode to form $FeCl_2$ (complexed as $KFeCl_3$ or K_2FeCl_4) and (2) the deposition of additional lithium in the Li-Al electrode. Corrosion of the iron current collector by this mechanism can be reduced by the addition of iron powder to the FeS electrode.

The normal IR included discharge cutoff voltage for Li-Al/FeS cells is 1.0 or 0.9V. The principal overdischarge reaction is

$$Al + 3LiCl \rightarrow AlCl_3 + 3Li$$

This reaction occurs at -1.5V (IR-free). Aluminum in the LiAl elertrode undergoes anodic oxidation to form $AlCl_3$, which is soluble in the electrolyte, and metallic lithium is deposited on the iron sulfide electrode. The cell under these conditions is in a state of reversal. Continuing to overdischarge eventually causes a short circuit due to the deposition of metallic aluminum in the separator or the formation of liquid lithium at the iron sulfide electrode.

The reaction at -1.5V (IR-free) is consistent with the maximum voltage observed (-1.6) during cell reversal tests that were performed at ANL.

Individual cell charge balancing (equalization) is required with Li-Al/FeS cells because small differences in the coulombic efficiency of the cells when cycled will produce a cell-to-cell charge imbalance. The cell to cell variation of coulombic efficiency is small and 10-cell series-connected modules have been operated with "equalization" charging being performed on a once-per-week basis. This observation suggests that van fleets could operate with an inexpensive bulk charger dedicated to each van (for overnight charging) while rotating a charger-equalizer unit among as many as seven or more vans. Concepts for inexpensive charger/equalizers for this battery system are under investigation in the EPRI program.

Periodic complete discharge is not necessary for this system.

B. Maintenance Requirements

Regular maintenance is not required because the battery is sealed and requires no electrolyte replacement. The battery temperature is controlled automatically to the proper operating temperature by the built-in heat exchanger (heating and cooling capability). The bulk charger (used for overnight charging) can also have a separate AC circuit that provides the power to the battery heaters for temperature maintenance for periods of intermediate storage (1-2 weeks). For longer term storage, the battery can be allowed to cool to room temperature and reheated to restore it to service. Periodic equalization (every 1-2 weeks) by a charger-equalizer unit is required. Equalization can be accomplished overnight.

The ANL van battery design[3] developed for the EPRI program packages individual cells into 9-cell module trays. Individual cells can be replaced in a planned maintenance step that provides a cool-down of the

battery to room temperature. An example that was described earlier (see Appendix C - Life Considerations) suggested that replacement of 5 cells in a 100 cell battery would significantly extend the battery life and be cost-effective.

VIII. PACKAGING FLEXIBILITY

A. Volumetric Considerations

The van battery design[3] which uses SOA Li-Al/FeS cells and is based upon the use of an electric Chrysler T-van provides a reference for volumetric considerations. The van battery is designed to fit the maximum space available under the deck, 75 x 30 x 12 inches. The energy output for this battery is projected at 36 kWh which yields a volumetric energy density of 82 Wh/l. A conservative packaging design was employed because space was available under the deck which did not infringe upon useable space within the vehicle. With refined packaging, values expected for the commuter car or van battery produced in the 1990's would be 100-125 Wh/l. Specific designs have not been attempted for the bipolar battery. A preliminary estimate puts the bipolar batteries in the range of 125-175 Wh/l.

B. Size Limitations

Cells have been built with two to seven electrode plates with the plate sizes ranging from 3 x 5 inches to 12 x 12 inches. The system as developed allows a great deal of flexibility in the size and capacity of the cells. The larger plate designs (i.e., 12 x 12 inches) have current distribution and heat removal requirements somewhat more demanding than the 5x7 inch size currently being developed for EV batteries.

C. Special Considerations

The battery design includes a high-efficiency insulating case, a heat-exchanger, voltage and temperature instrumentation taps packaged as a single unit. A small blower will be mounted adjacent to the battery to circulate the cooling air.

D. Scale Effects

Scaling factors for batteries in the range of interest i.e., 10-50 kWh have not been developed. Based upon the flexibility available in the cell design, i.e., size, thickness, and number of plates, efficient cell designs can be developed for batteries that span the 10-50 kWh range.

The battery shape, which is determined by the application, influences the surface/volume ratio of the battery and has an important effect upon volumetric energy density because of the need for an insulating case. The impact of shape upon the gravimetric energy density is less important. For the prismatic battery designs that have been studied thus far discount factors of 0.5 to 0.6 have been obtained that convert cell volumetric energy density to battery volumetric energy density. The discount factors developed by design studies for the gravimetric energy density have ranged from 0.75-0.8. Preliminary cell design studies have been completed for bipolar cells. Scaling factors and discount factors for bipolar cells packaged as a battery unit have not as yet been developed.

ACKNOWLEDGEMENT

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APPENDIX A - PRISMATIC BATTERY PERFORMANCE PROJECTIONS

I. Specific Energy Projections

The specific energy as a function of constant power discharge was obtained from an estimate based upon a high-power cell built and tested by T. Kaun.

The values projected by T. Kaun(1) are given in Table A-1.

Table A-1 Specific Energy with Constant Power Discharge

Discharge Rate (W/kg)	Specific Energy (Wh/kg)
6	111
11	107
25	100
47	93
82	82
126	63

The state-of-the-art and projected specific energy for cells having P/E ratio = 2 was obtained from modeling studies.(2) These values are given in Table A-2.

(1) T. Kaun, Private communication, Argonne National Laboratory, March 1981.
(2) E. Gay, Private communication, Argonne National Laboratory, Jan. 1984.

Table A-2 Specific Energy, Wh/kg

Technology State	Cells	Batteries*
SOA	87	65 @ 16 W/kg
Projected (1990)	115	86 @ 21 W/kg

*Derating factor of 0.75 (from cells to batteries).

These values are plotted on Fig. A-1 which provides the basis for the SOA and projected values for the specific energy of Li-Al/FeS batteries as a function of constant power discharge rates.

II. Peak Power Projections

The peak power estimates are based upon a shape factor obtained from the estimates based upon an experimental high-power cell and modeling studies for cells with a P/E ratio of 2.

These values are plotted in Fig. A-2.

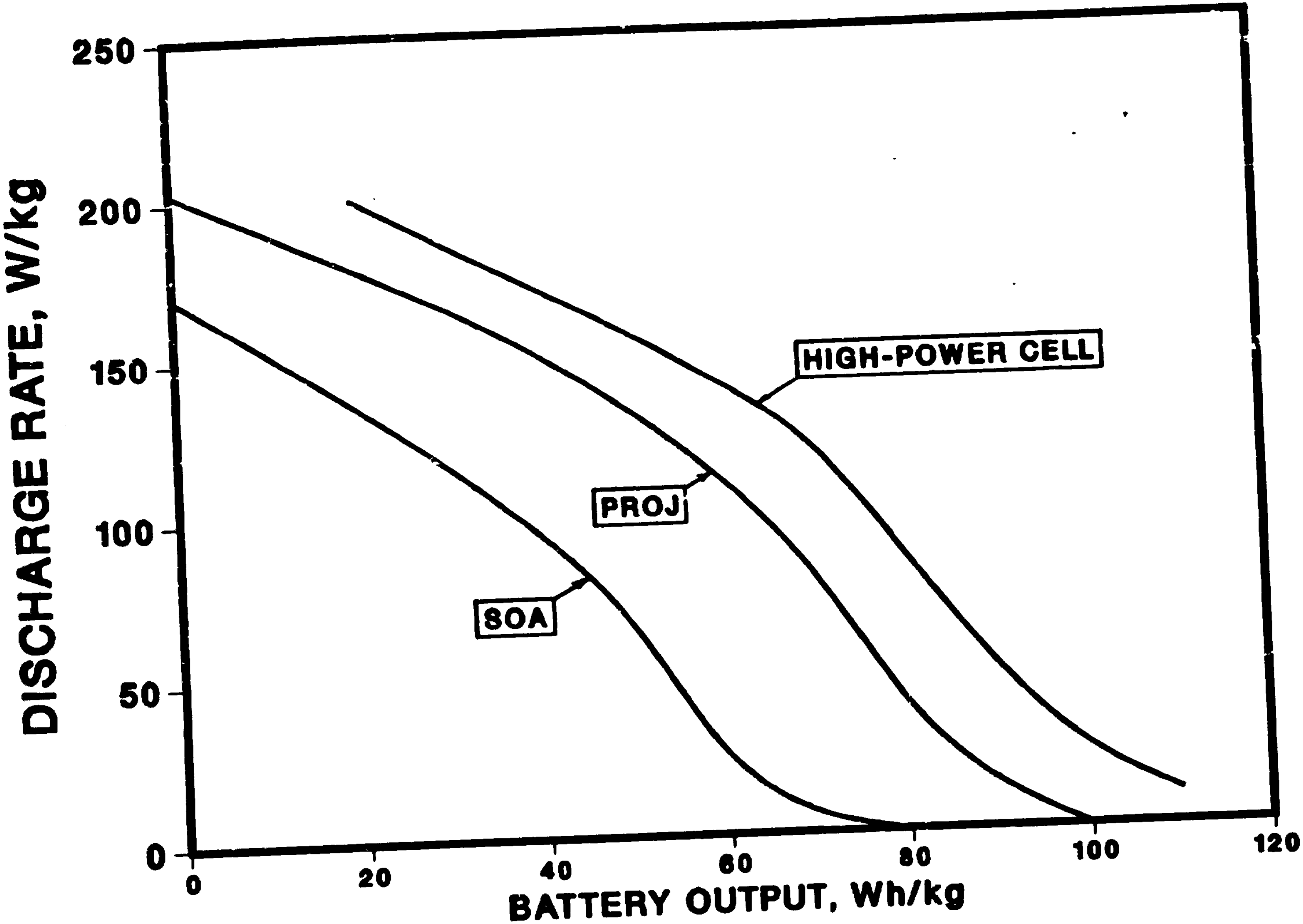


Fig. A-1. Specific Energy of Prismatic Li-Al/FeS Batteries.

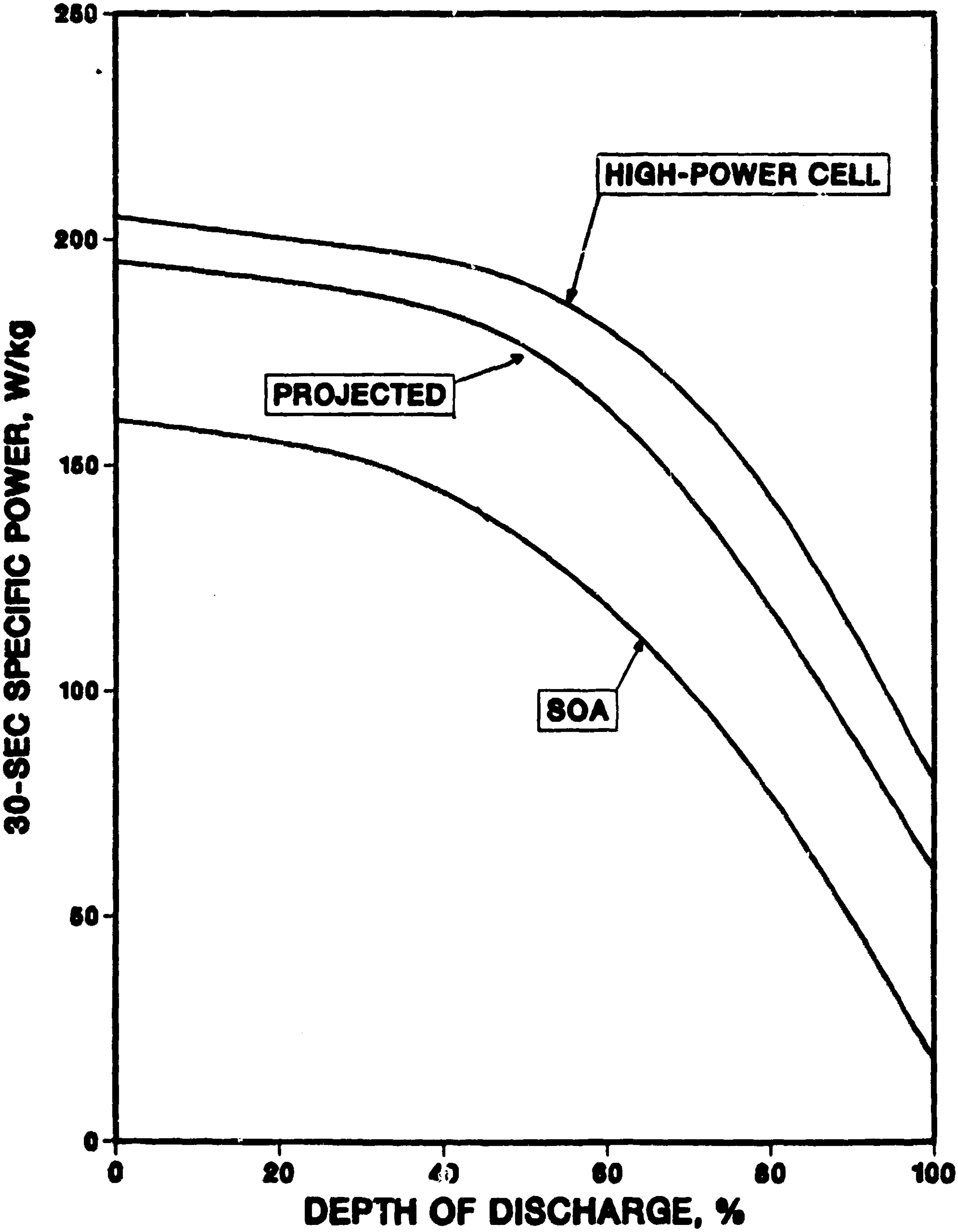


Fig. A-2. Peak Power of Prismatic Li-Al/FeS Batteries.

APPENDIX B - BIPOLAR BATTERY PERFORMANCE PROJECTIONS

A study was made to characterize the projected performance of the bipolar type Li-Al/FeS batteries. The study was focused on the following:

1) Specific energy of a battery when discharged at a constant specific power.

2) 30-second specific power capability of the battery as a function of the state-of-charge (SOC) as defined for the standard C/3 rate.

I. Description of Bipolar Type Li-Al/FeS Cell Batteries

The cell considered in the study employs Li-Al/LiCl-KCl/FeS operating at about 460°C with open circuit voltage of 1.35 V at the fully charged state. The bipolar cell discussed in this study comprises stacked layers of circular electrodes, 0.2 cm thick ceramic (MgO powder) separators, a ceramic (MgO) ring insulator, and a 0.018 cm thick stainless steel can. The bipolar plates are made of 0.018 cm thick stainless steel. As we will discuss later, an electrode diameter of 17.78 cm (thick) with a three bipolar plates was found to satisfy the requirements.

II. Methodology

For the analysis, a conceptual cell design was developed by first selecting mechanical dimensions and a theoretical capacity and applying key design parameters including loading densities and the negative/positive ratio. The cell design was then used to calculate 1) specific energies at different rates of discharge, and 2) 30-second peak specific powers at different states of charges as defined. Flow charts of the computer programs used to carry out the analysis are shown in Fig. B1 and B2.

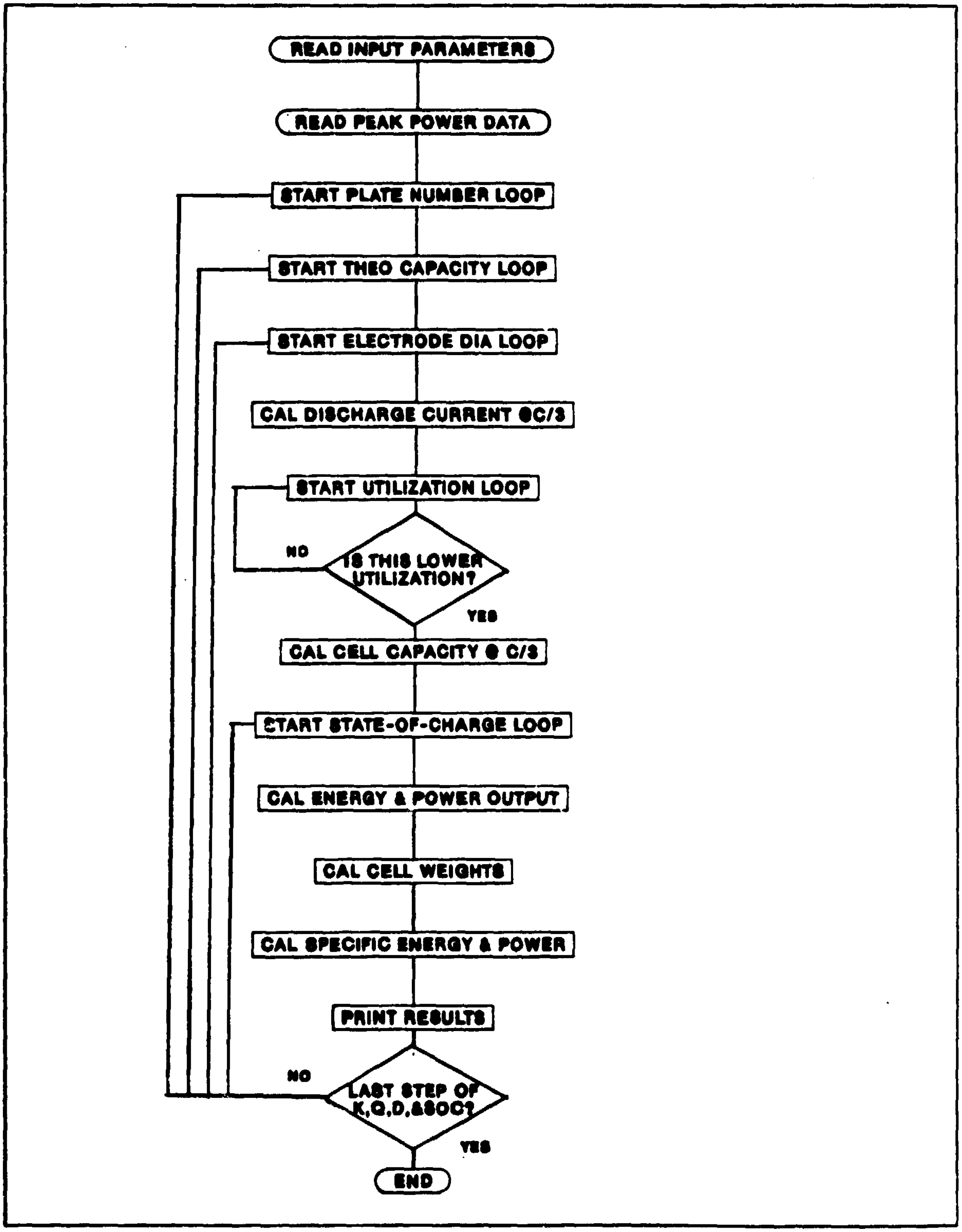


Fig. B-1. Computer Flow Chart for Specific Energy.

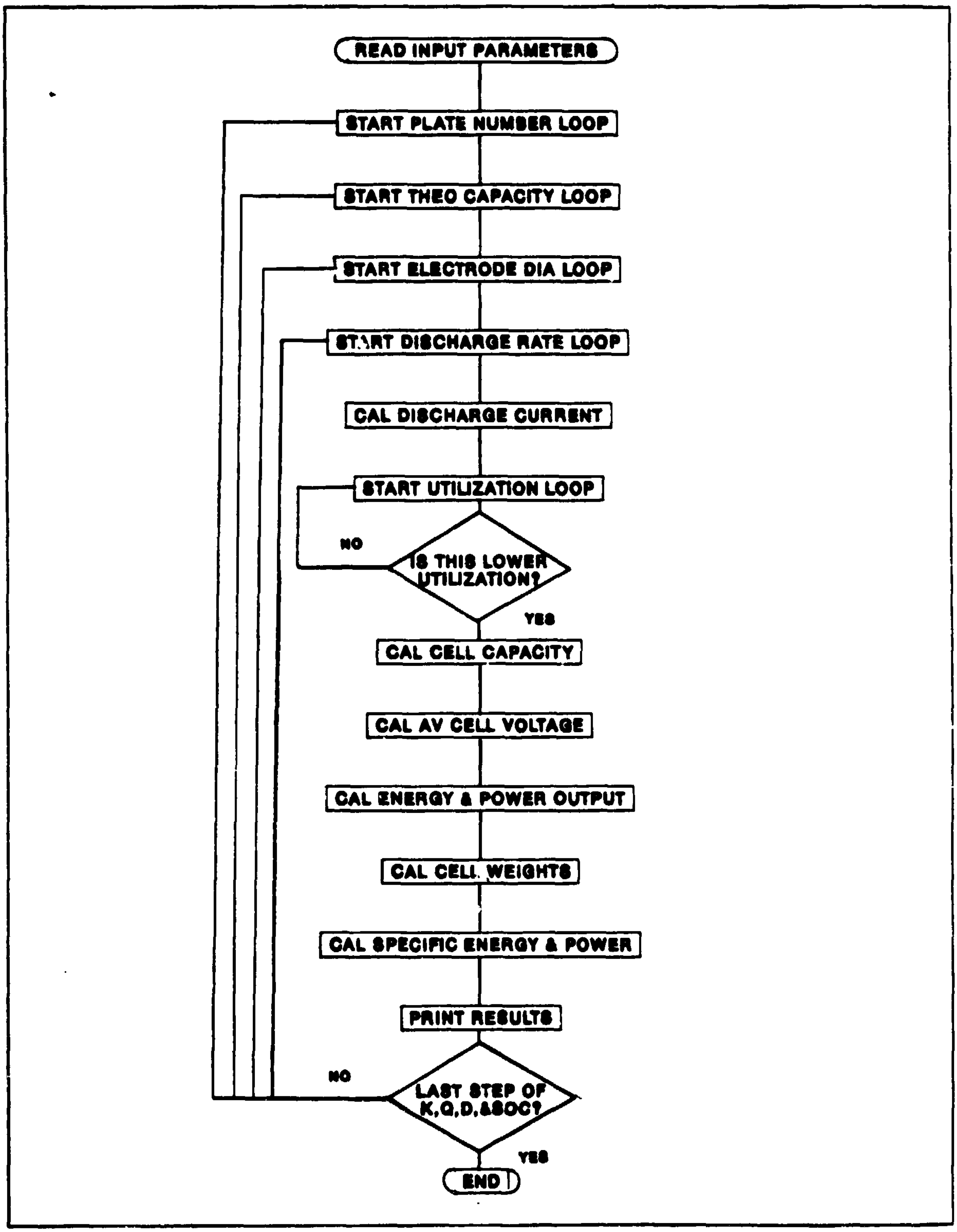


Fig. B-2. Computer Flow Chart for Peak Power.

In calculating the specific energies, the utilization of the active material in the cell at the desired discharge rate must be determined. For this, the following formula which is derived from experimental data on an advanced prismatic cell was used.[1]

$$U(\text{current}) = 1 - 1.67\ i$$

where i is in A/cm^2.

The utilization is also known to be affected by the electrode thickness although its effect diminishes as the thickness decreases particularly below 0.15 cm. The effect is analytically expressed by the following formula based on an experimental correlation.[2]

$$U(\text{thickness}) = 1.15 - tc$$

where tc is the positive electrode thickness in cm. Two values of the above utilizations were then compared and the smaller value was taken to determine the discharge capacity of the cell at the selected rate. For determining the average cell voltage, the following equation was used.

$$V_{av} = 1.35 - R \cdot i$$

where V_{av} is in volt, R is cell resistance in ohm·cm^2, and i is current density in A/cm^2. The cell resistances were taken as 0.8 for advanced and 1.2 for the SOA cells. These values are similar to those found for the prismatic cells. The energy and power outputs of the cell can be calculated by multiplying the average voltage by the cell capacity and current, respectively.

For the calculation of the peak power, one needs to know the peak-power flux, W/cm^2. Data for 30-sec peak power are available for SOA and

1) ANL-80-128, p. 46 (1981).
2) Gay, E., Private communication (1983).

an advanced prismatic cell[4] as a function of the SOC. The values are listed below:

	80% SOC	50% SOC	30% SOC	10% SOC
Advanced, W/cm^2	0.57	0.41	0.32	0.25
SOA, W/cm^2	0.40	0.25	0.17	0.10

These values are observed for the prismatic cells, and even higher values are expected for a bipolar type cell because of its intrinsically low cell resistance. The cell values obtained were multiplied by 0.75 to allow for the weight of the battery case and other battery components.

III. Summary of Results

A series of computations were made for both the advanced and SOA designs with the electrode diameter varying from 3 in. (7.62 cm) to 7 in. (17.78 cm), the cell capacity varying from 100 to 300 Ah, and the number of bipolar plates varying from 1 to 3. For both the advanced and SOA design, the cells having 7 inch electrodes, 3 bipolar plates and theoretical capacity of 180 Ah were selected because they provided the best P/E match to the requirements. The results are summarized below and also presented in Fig. B3 and B4.

1. Specific energy of a battery when discharged at a constant specific power

	20 W/kg	60 W/kg	80 W/kg	100 W/kg	200 W/kg
Advanced, Wh/kg	136	115	103	90	30
SOA, Wh/kg	121	97	83	69	-

2. 30-second specific power capability as a function of the SOC.

	80% SOC	50% SOC	30% SOC	10% SOC
Advanced, W/kg	242	187	146	114
SOA, W/kg	167	104	71	42

4) Redey, L., Private communication (1982).

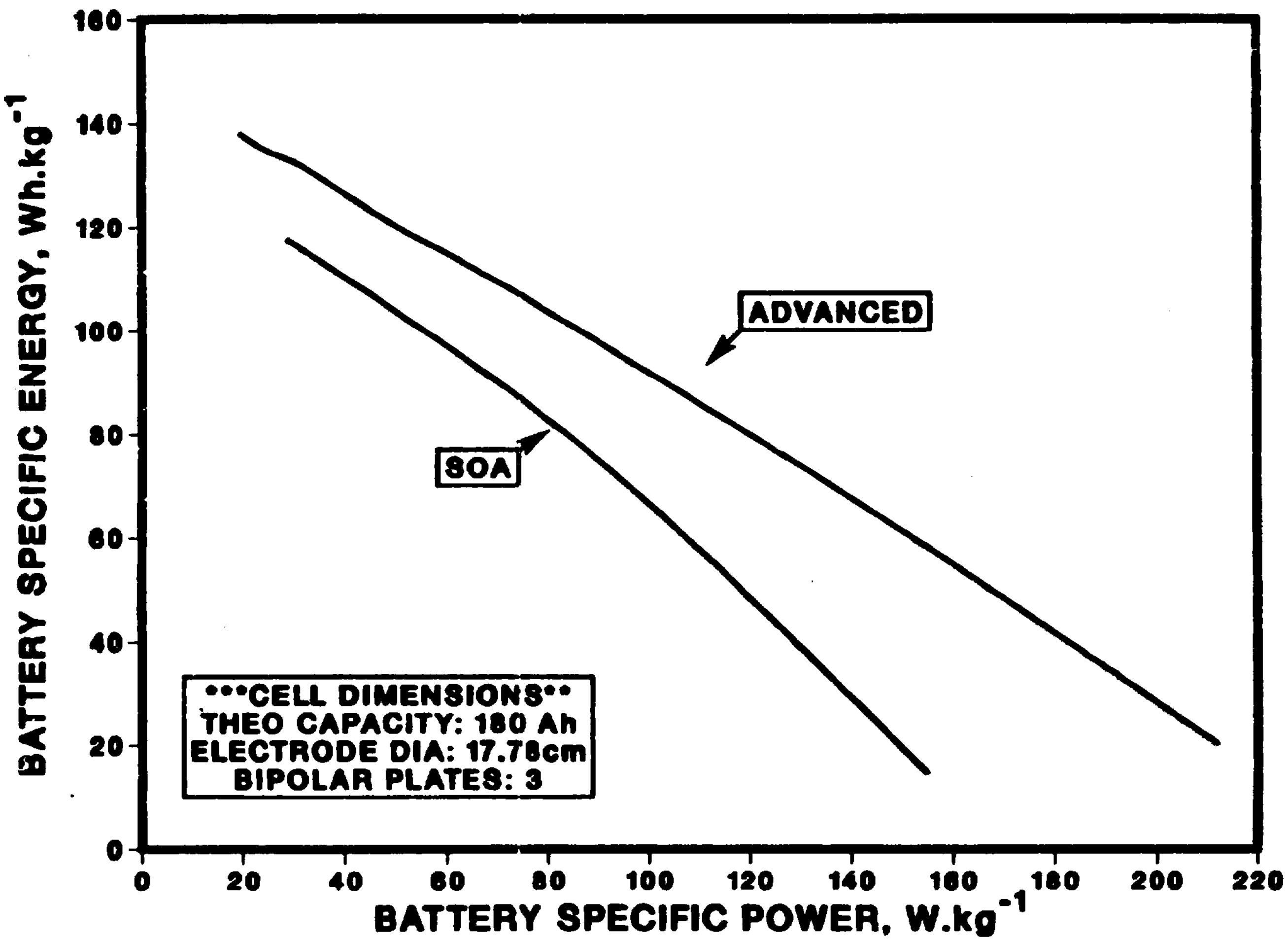


Fig. B-3. Specific Energy as a Function of Constant Power Discharge.

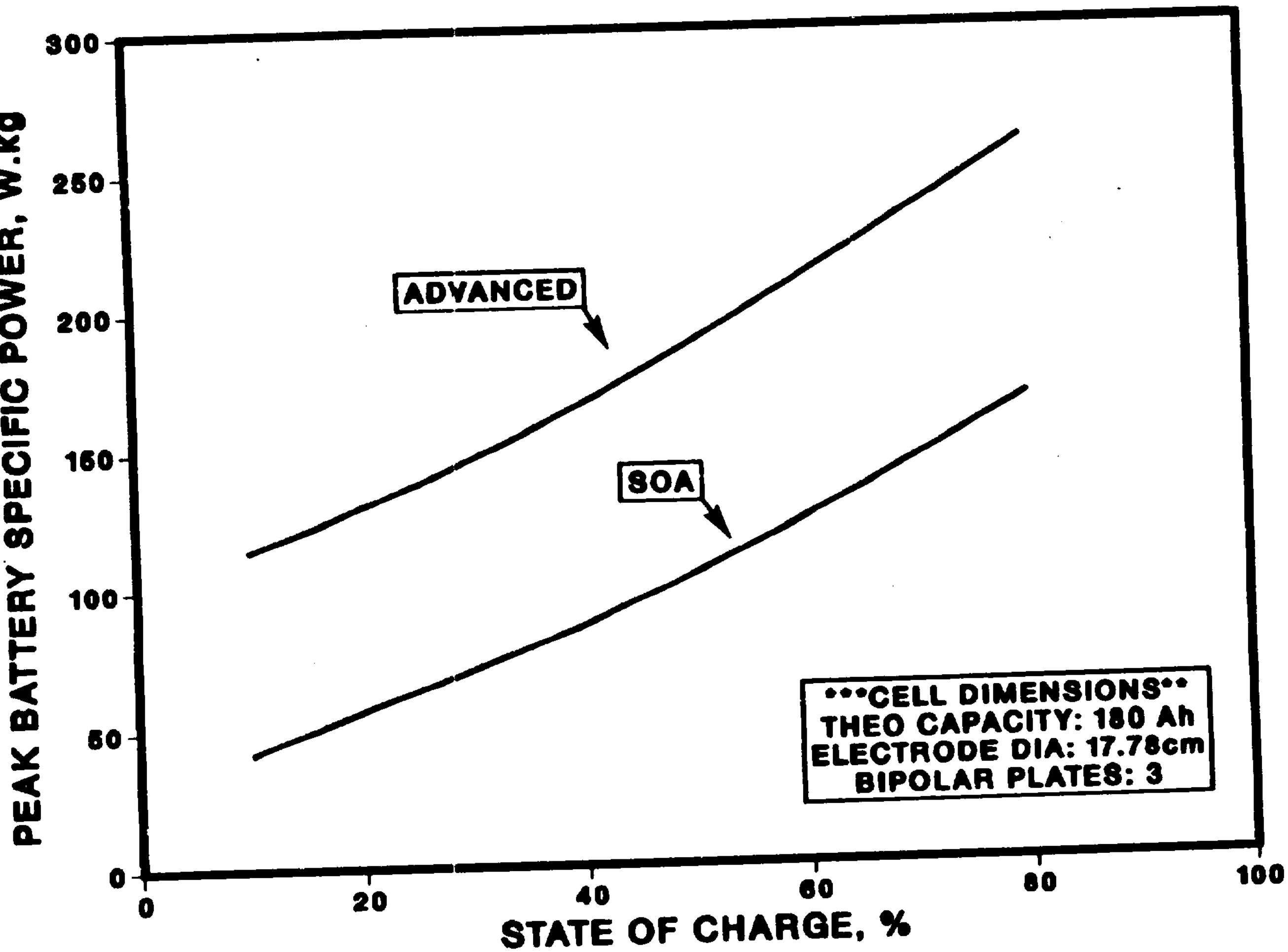


Fig. B-4. Specific Power (30-sec) as a Function of State of Charge.

The cell design parameters and cell dimensions used in the analysis are summarized in Tables B1 and B2.

Table B1. Cell Design Parameters

Cell Electrode Dia	17.78 cm
Electrode Area	744.5 cm^2
No. of Bipolar Layers	3
Theoretical Capacity	180 Ah

	Advanced	SOA
Neg Loading Density, Ah/cm^3	1.0	0.8
Pos Loading Density, Ah/cm^3	1.6	1.4
Neg/Pos Ratio	1.1	1.1
Cell Resistance, ohm cm^2	0.8	1.2
Cell Thickness, cm	1.94	2.21
Cell Weight, kg	1.23	1.34

Table B2. Cell Dimensions

	Advanced	SOA
Electrode Dia, cm	17.78	17.78
No. of Bipolar Layers	3	3
Electrode Area, cm^2	744.5	744.5
Electrode Thickness		
Positive, cm	0.151	0.173
Negative, cm	0.266	0.332
Separator, cm	0.200	0.200
Can, cm	0.018	0.018
Total Thickness, cm	1.941	2.21
Total cell volume, cm^3	733	833
Total cell weight, kg	1.228	1.344

APPENDIX C - BATTERY MANUFACTURING COST PROJECTIONS

I. INTRODUCTION

The potential for low-cost battery manufacture is explored here by (1) the use of the Gould cell technology (powder MgO separators) (2) manufacture of all the required lithium containing compounds from a Li_2CO_3 feedstock (3) use of low-carbon steel* for the cell container, electrode structure, and particle retainers (mechanically perforated sheet), and (4) manufacture of the cell in a discharged state, i.e., use of Li_2S as the source of electrochemically active lithium.

The cost impact of the LiBr-LiCl-LiF electrolyte versus the LiCl-KCl electrolyte is examined by choosing the Li-Br containing salt for a high-power battery and the LiCl-KCl electrolyte for a high-energy battery.

II. MATERIALS COST

The market price of materials of interest for this analysis is given in Table C1.

Starting with a feedstock of Li_2CO_3, H_2S, HF, HCl, H_2SO_4, and NaBr, the feedstock costs to make a pound of Li_2S, LiBr, LiCl, and LiF (as required for the high-power cell) is listed and compared with market prices in Table C2.

*LiAl was chosen as the negative active material to permit the use of low-carbon steel for the negative electrode housing.

Table C1. Market Price of Materials* (1983)

Material	Market Price, $/lb
Lithium metal	31.00
Li_2CO_3	1.48
LiCl	3.00
LiF	4.72
KCl	0.105
HCl	0.27
HF	0.68
H_2S	0.11
H_2SO_4	0.04
NaBr	1.04
MgO	0.50
Al	0.60
Iron powder	1.00
Low Carbon Steel	0.33
KCl	0.10

*Chemical Marketing Reporter, Nov. 11, 1983.

Table C2. Feedstock/Market Price Comparison

Compound	Feedstock Cost,† $/lb of Compound	Market Price* of Compound, $/lb	Feedstock Cost as % of Market Price
Li Metal	9.29	31.00	30
Li_2S	2.48	**	-
LiBr	1.88	6.50	29
LiCl	1.52	3.00	51
LiF	2.63	4.72	56

*Chemical Marketing Reporter, Nov. 11, 1983.

**Not made in commercial quantities.

†Includes Li_2CO_3 plus all reactants to convert Li_2CO_3 to the compound listed.

III. COST OF CONVERTING $LiCO_3$ TO THE DESIRED COMPOUNDS

The feedstock cost for the conversion of Li_2CO_3 to the desired compounds Li_2S, LiBr, LiCl, and LiF is given in Table C3.

Table C3. Feedstock Cost for a High-Power Battery

Basis

1. 5 lb of electrolyte per kWh
2. Electrolyte composition, wt.%
   LiBr, 68; LiCl, 22; LiF, 10.
3. 0.67 lb elemental Li req'd per kWh in 2.2 lb Li_2S

Compound	Cpd Wt lb/kWh	Feedstock Cost $/lb Cpd	$/kWh
Li_2S	2.2	2.48	5.45
LiBr	3.4	1.88	6.39
LiCl	1.1	1.52	1.67
LiF	0.5	2.63	1.31
Totals	7.2		14.82

The conversion cost of the feedstock was estimated using the following assumptions.

1. The equipment cost, depreciation base, total investment, rent and labor costs are 1/2 of that estimated for the battery plant in ANL-79-59 p. 15 (ADL Method, Table 11). The values for the chemical conversion part of the plant are:

Equipment Cost, $\$x10^6$	2.33, $2.03/kWh (1979 $)
Depreciation Base, $\$x10^6$	4.68, $4.07/kWh
Total Investment, $\$x10^6$	8.68, $7.55/kWh

Total Labor, $/kwh 2.13

2. Inflation rate = 1.099 x 1.096 x 1.062 = 1.28.

3. Battery size = 24 kWh

4. Plant size 1.15 x 10^6 kWh/year

The conversion cost of Li_2CO_3 to the desired lithium compounds is shown in Table C4.

Table C4. Production Cost of Li_2S + LiBr-Containing Electrolyte from Feedstock

Materials Cost = \$14.82/kWh (Table 3)

Item	Cost Item	\$/Battery	Remarks
1	Materials Cost	356	
	Materials OH	35	10% of materials cost
		391	
2	Direct Labor	65	
	Labor OH	182	280% of direct labor
		247	
3	Equipment Depreciation	13	
	Rent	4	
		17	
4	Factory Cost	655	Item 1 + 2 + 3
5	ROI + Taxes	70	30% of total investment
6	Production Cost, \$/battery	725	
	, \$/kWh	30.21	

The cost of the non-lithium-containing materials is given in Table C5.

Table C5. Non-Lithium-Containing Materials

Material	Wt/kWh	\$/lb	\$/kWh
Aluminum	2.5	0.60	1.50
Iron Powder	3.5	1.00	3.50
MgO	1.9	0.50	.95
L.C. Steel	7.0	0.33	2.31
Feedthru Parts	-	-	4.80
Totals	14.9	-	13.06

The feedstock cost for producing Li_2S and LiCl for the high-energy battery is given in Table C6.

Table C6. Feedstock Cost for Producing Li_2S and LiCl for the High-Energy Battery

Compound	Cpd Wt/kWh, lb	Feedstock Cost \$/lb cpd	\$/kWh
Li_2S	2.2	2.48	5.45
LiCl*	2.2	1.52	3.34
Totals	4.4	-	7.79

*5 lbs of electrolyte with 44 wt.% LiCl-56 wt.% KCl

The production cost of Li_2S and LiCl from the feedstock is given in Table C7.

Table C7. Production Cost of Li_2S and LiCl From Feedstock

Basis

Materials Cost $7.79/kWh (Table C6)
Capital, Labor, Rent is 25% of Battery Plant in ANL-79-59

Item	Cost Item	$/Battery	Remarks
1	Materials Cost	187	
	Materials Overhead	19	10% of materials costs
		206	
2	Direct Labor	33	
	Labor Overhead	92	280% of direct labor
		125	
3	Equipment Depreciation	7	
	Rent	2	
		9	
4	Factory Cost	340	
5	ROI + Taxes	35	
6	Production Cost	375 ($15.60 kWh)	

IV. OEM SELLING PRICE

A summary of the costs leading to the estimation of the OEM selling price is given in Table C8. A comparison is made between a high-power battery that employs LiBr-LiCl-LiF electrolyte with a high-energy battery using LiCl-KCl electrolyte.

Table C8. OEM Selling Price for Lithium-Metal Sulfide Batteries
(Battery Size - 24 kWh)

Cost Item	1983 Dollars/Battery High-Power	1983 Dollars/Battery High-Energy	Remarks
Materials			
Lithium Bearing Compounds	725	375	Table C4 (High-P); Table C7 (High-E)
Other Materials	313	320	Table 5; Table C5 + $7 for KCl
Insulating Enclosure	650	650	Consiglio/Symons estimate
	1,688	1,345	
Material Overhead	169	135	10% of materials
	1,857	1,480	
Direct Labor			
Cell	131	131	ANL-79-59 x inflation
Cell/Battery	33	33	25% of cell labor
	164	164	(Consiglio/Symons)
Direct Labor Overhead	459	459	280% of direct labor
	623	623	
Equipment Depreciation	25	25	ANL-79-59 x inflation
Rent	8	8	ANL-79-59 x inflation
Factory Cost	2,513	2,136	
Capital Investment			
Working Capital			
Equipment			
Total Investment	464	464	ANL-79-59 x inflation
ROI + Taxes	139	139	30% of total investment
Warranty	100	100	Consiglio/Symons study
OEM Selling Price	2,752 ($115/kWh)	2,375 ($99/kWh)	

V SUMMARY

1. The main objective of this study was to show that by the use of Li_2CO_3 as a feedstock for the production of all the required lithium-containing compounds, it may be possible to reduce the battery OEM price to about $100/kWh.

2. The ADL costing methodology was followed except where modified by the Consiglio/Symons study. The capital values for equipment, depreciation, and total investment as well as rent were taken from the ANL-79-59 study on cost.

3. Based upon this approach, a trade-off analysis for a high-power system (using the LiBr containing electrolyte) shows a 15% higher cost compared to the system using LiCl-KCl electrolyte ($115/kWh compared to $99/kWh).

4. It seems likely that the power and energy requirements for the commuter car and van can be met using prismatic cell designs optimized for power using LiCl-KCl electrolyte, a Li-Al electrode (to permit use of low-carbon steel for the negative electrode structure) and low-carbon steel for the cell can. By addition of iron powder (a 30% stoichiometric excess) to the positive electrode mix, it would be possible to use low-carbon steel for the positive electrode structure. Mechanically perforated steel sheet in series with the MgO powder separator can probably be used successfully as a particle retainer.

As indicated in Table C8, the OEM cost for such a battery would be $99/kWh.

5. A cost analysis for the bipolar battery was not attempted. For purposes of this study, no distinction between prismatic or bipolar battery manufacturing cost was made.

APPENDIX D - LIFE CONSIDERATIONS

A. Cells

A summary of the cycle-life tests for the Gould and Eagle-Picher status cells is presented in Table D1. For the purposes of cycle-life testing, a deep cycle was defined as 80% or greater of the theoretical cell capacity, and end of cell life was defined as either a 20% loss of the initial capacity or a drop in the coulombic efficiency to 95%. Groups of at least 12 cells of identical design were cycle-life tested to provide statistical data on the time to failure. The highest mean time to failure (MTTF) was 410 cycles for the Eagle-Picher Group I cells and 330 cycles for the second group of Gould powder separator cells. The Weibull Slope, which defines the distribution of failures, ranged from 1.4 to 3.2. The average capacity loss rate ranged from 2.5 to 8% per 100 cycles.

Significant lifetime improvement was demonstrated by a group of five cells built by Eagle-Picher in a program for the U.S. Army (MERADCOM). The cycle life of the five cells is plotted against the voltage at cut-off at 80% depth of discharge (see Fig. D1). The testing of this group continues with two of the cells having exceeded 1000 cycles. The average capacity loss rate for a cell in this group has been measured at 2%/100 cycles.

Life limiting mechanisms for the cells have been studied extensively by the post-test examination of hundreds of cells. The cells fail by shorting caused by the extrusion of active material from the negative or positive electrode due to ruptures in the electrode containment structures or by shorting caused by the formation of Li-Al protrusions that penetrate the BN separator.*

*This failure mechanism has been experienced only in the Eagle-Picher cells.

Table D1. Summary of Li/FeS Cell Performance Tests at ANL

	Gould Status Cells			Eagle-Picher Status Cells			
	I	II		Group I	Group III	Group VI	Group IX
No. of Cells in Group	12	12		14	12	12	12
Theo. Capacity, Ah	194	194		360	394	394	394
Av. Operating Temperature, °C	465	a		465–475	475–490	470–480	465
Av. Peak Capacity, Ah	158	157		288	294	347	340
Std. Deviation in Peak Capacity, ± %	4.5	3.2		5.2	6.6	0.9	2.1
Av. Specific Energy, Wh/kg	74	80		71	81	94	90
Peak Specific Power, W/kg	70	70		55	55	74	80
Cycle Life[b]							
High/Low, Cycles	307/14	467/121	542/158*	1031/238	908/23	201/100	517/193
Mean Time-to-Failure, Cycles	218/26[c]	268	330	410	362	138	345
Weibull Slope	2.0/3.4	3.1	2.9	2.9	1.4	2.1	3.2
Av. Capacity Loss Rate, % per cycle		0.08	0.06	0.032	0.027	0.045	0.024

[a]Temperature was 455°C until 20% capacity loss, then raised in 5° increments to 455–475°C.

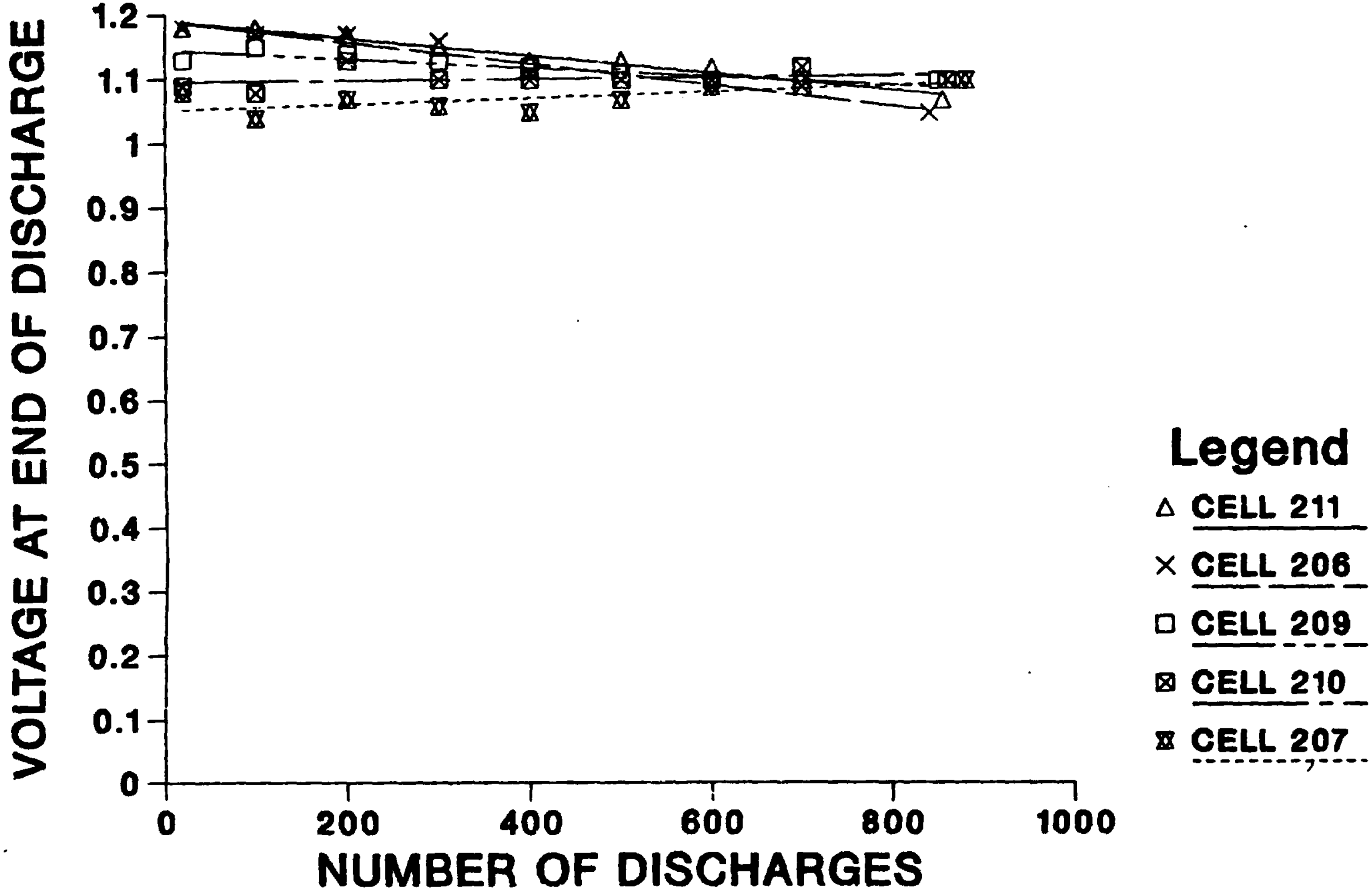
[b]End of life defined as 20% capacity loss or coulombic efficiency decrease to <95%.

[c]Correlated as five- and seven-cell groups. Single group correlation not possible.

*Gould Status Cells, Group II, showing the improved performance obtained by raising the temperature to 475°C.

FIG. D-1

CYCLE LIFE OF MERADCOM CELLS



The Gould cells which employ a MgO powder separator fail by the gradual degradation of the separator which allows the electrodes to contact or by the gradual buildup of iron particles in the separator that eventually bridge and cause a short.

An analysis relating the MTTF and the failure distribution of cells on the expected battery life is given in Section C.

B. Modules

The cycle life achieved by Li-Al/FeS modules tested under deep discharge conditions at ANL and Eagle-Picher, Industries is given in Table D2. In general, the cycle life obtained was that expected based upon cell life results obtained from tests of individual cells. The exception occurred in the test of the 30 cell module which failed early in life due to electrolyte leakage from hairline cracks which developed in several of the cells. The cell cans are at negative potential and fail rapidly when the electrolyte bridges cells in a closely packed cell array. This condition causes an electrolysis reaction resulting the transfer of iron accompanied by rapid discharge of the cells.

Module testing at ANL is continuing in the Electric Power Research Institute (EPRI) program. A 9-cell array of Gould cells will be tested in a fully-engineered system that includes heating and cooling units in a high-efficiency thermal insulated case.

C. Batteries

Test work at ANL has shown that a series-connected module can continue to operate for many cycles with a small percentage of failed cells.(1) Tests were also performed on individual cells with a procedure that simulated

(1) ANL Report, ANL-81-65 pp. 42-46 (February 1982).

Table D2. Module Tests

Year	No. of Cells	Battery Voltage V	Battery Capacity kWh	Thermal Insulation	Cycle Life
1977	6	8.8	1.0	Vac-Foil	11
1979	10	5.9	3.7	Conventional	34
1979	5	5.6	1.6	Vac-Foil	70
1980	9	10.6	3.0	Conventional	72
1981	10	12	2.5	Vac-Foil	71
1981	10	12	2.5	Vac-Foil	79
1981	10	11.6	3.8	Conventional	270
1981	10	11.8	4.0	Conventional	150
1983	30	36	12	Conventional	12*

*Module failed early in life due to electrolyte leakage from several defective cells (see text).

the behavior of a failed cell in a series-connected string.[2] Cells that had developed a short as a result of lifecycle testing were tested using a timed cycle in which 284 Ah were passed through the cell both on charge and discharge with the voltage and heating rates monitored. The voltage history of such a cell is given in Fig. D2. The main points to be noted are that the shorted cell provides useful voltage for a number of cycles (30-40 cycles) as shown by the curve labeled 2 until it deteriorates to the condition shown by curve 3 where the cell exhibits its peak negative voltage of -1.6 V and its maximum heat generation of 90-100 W on discharge. The duration of this peak negative voltage state was 15-30 cycles when it then tended to a terminal state shown by curve 4. Voltage conditions for the terminal state are -0.4 V on discharge and +0.4 V on charge with heat evolution of 35-40 W on discharge and 15-20 W on charge.

The main conclusion that has been drawn from these tests is that it may be possible to operate a series-connected battery containing a small number of failed cells if provision is made to handle the extra heat generated by the failed cells. This conclusion provides the rationale for considering maintenance schemes that allow the battery to operate until the number of failed cells in the battery drops the capacity below an acceptable level at which time the battery is shut down and the failed cells are replaced.

A battery life analysis for Li-Al/FeS cells with a projected MTTF of 1500 and a Weibull slope of 5 was developed. The assumptions made were (1) initial capacity of 20 kWh delivered by a 100 cell battery (2) 2%/100 cycle capacity loss rate (3) average voltage loss per failed cell of 2.4 V and (4) 80 miles/discharge.

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(2) ANL Report ANL-83-62 pp. 55-58 (September 1983).

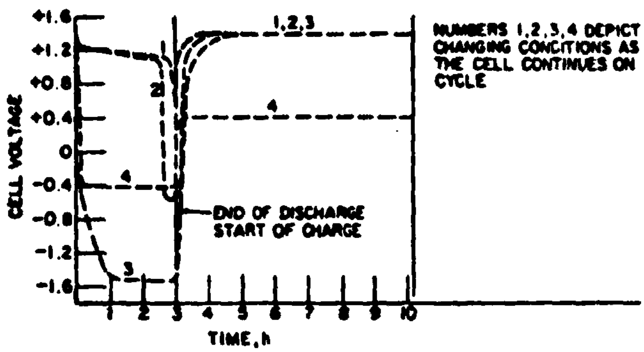

Fig. D2. Typical Voltage of A Short-Circuited Cell on Continued Cycling.

The distribution of failures with cycle-life is given in Fig. D3. Using this data, the battery output as a function of cycles was derived and is shown plotted on Fig. D4. The results show that a battery life of 1000 cycles is possible with the replacement of 5 cells.

Whether it is economical to repair the battery after the first few cells fail will depend upon the cost of repair and the lifetime extension obtained compared to the cost of purchasing a new battery. An example developed in Table D3 suggests that maintenance for an additional 16,000 miles (200 cycles) obtained by replacing 5 cells would be cheaper; that is, amortizing battery first cost over 64,000 miles (800 cycles) results in a cost of 4.7¢/mile while the $600 spent for maintenance provides an additional 16,000 miles and results in a cost of 3.75¢/mile.

To summarize:

1. State-of-the-art cells at the engineering level have shown the potential for achieving >1000 cycles MTTF.

2. Statistical distribution for cells as determined by Weibull analysis show distributions characterized by slopes of 2-3. The potential for improvement to distributions characterized by a Weibull slope of 5 appears good.

3. Typical module tests resulted in obtaining module lifetimes that could be projected from consideration of single cell lifetime data. One module test was abruptly terminated due to electrolyte leakage from cells.

4. Experimental work at ANL with cells and modules has demonstrated the operation of a module with several failed* cells. Individual cells were tested in a mode simulating the operation of a failed cell in a series-connected

*Failure defined by the single cell test criteria of (1) less than 80% of initial capacity or (2) less than 95% coulombic efficiency.

FIG. D-3

FAILURE RATE FOR CELLS WITH MTTF OF 1500 CYCLES

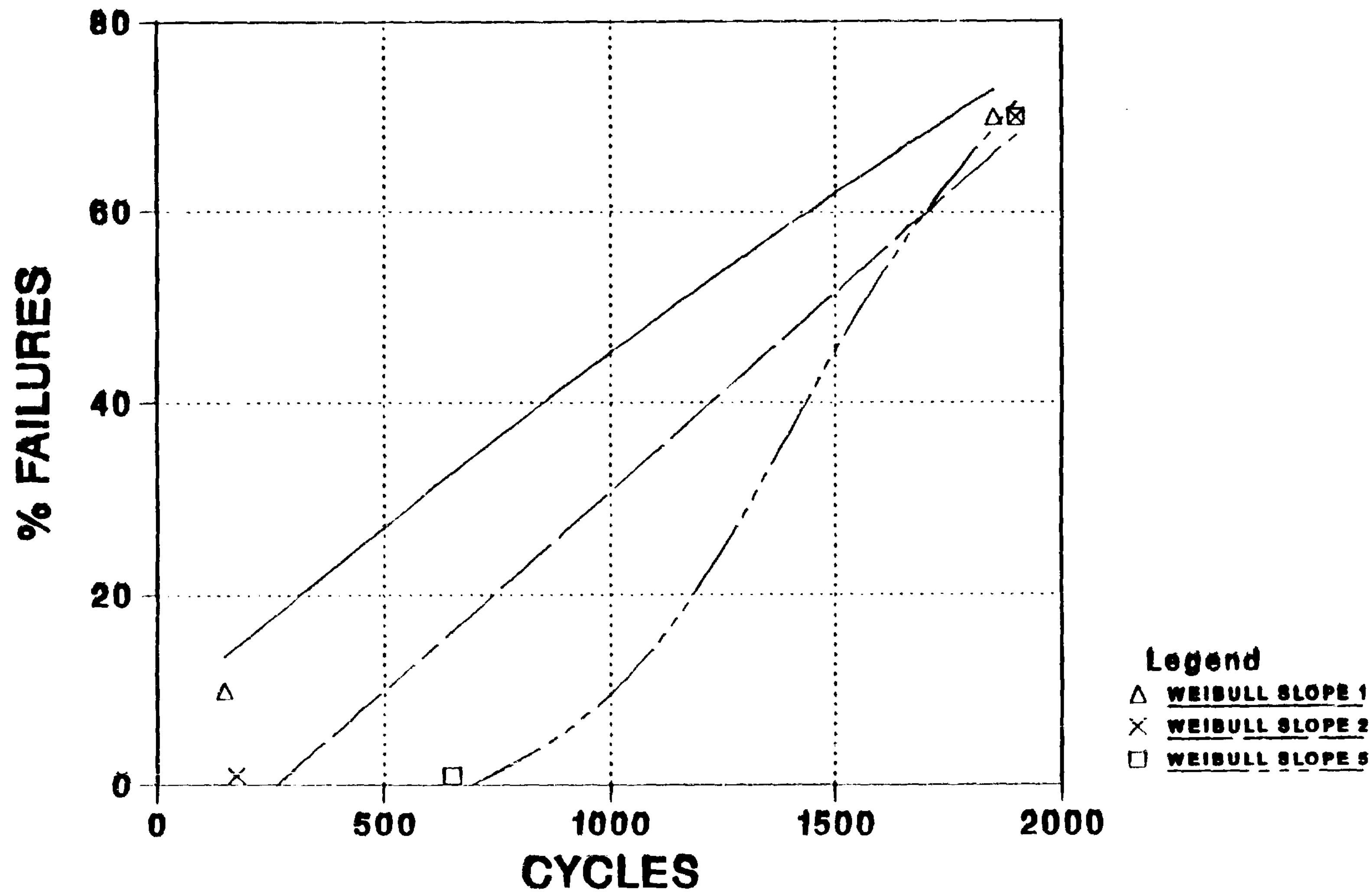

Fig. D-4. Effect of Cell Replacement on Battery Life.

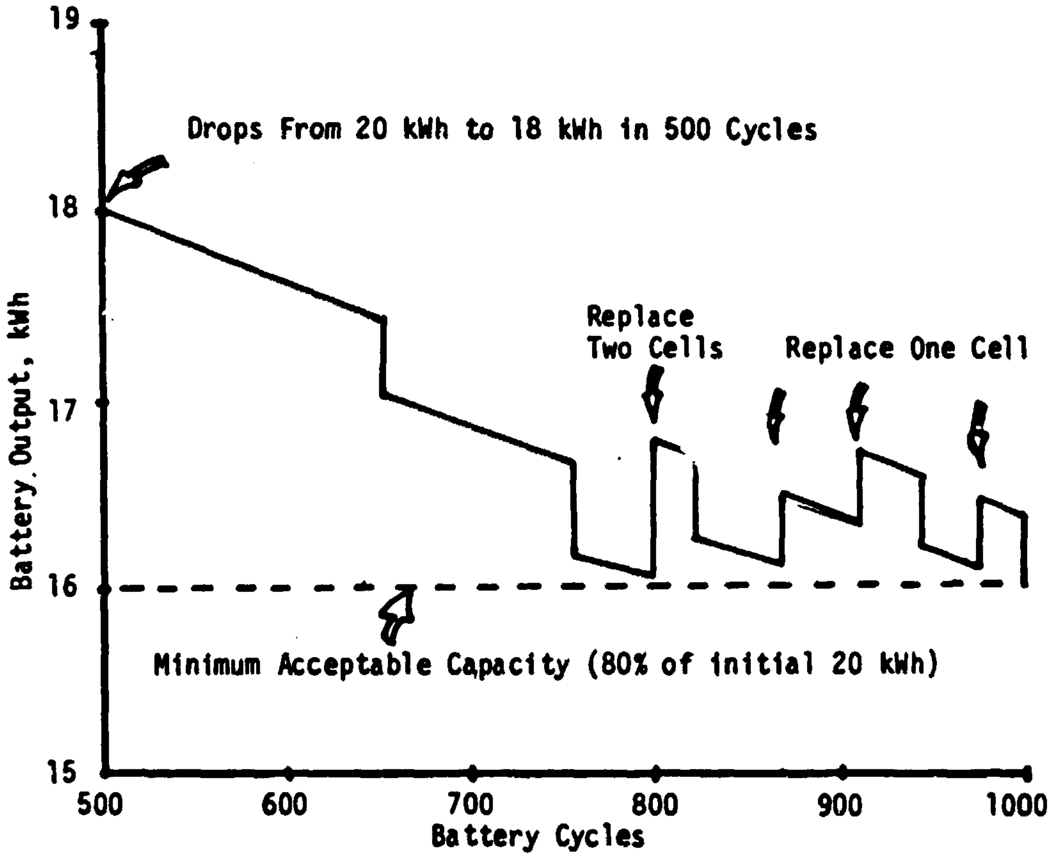

Table D3. Battery Maintenance Cost for an Electric Automobile

Cycle No.	Cumulative Miles	Maintenance Work	Cost[a]
1-800	64,000	none	$3,000 (Battery purchase)
800-870	69,600	2 cells replaced	210
870-910	72,800	1 cell replaced	130
910-975	78,000	1 cell replaced	130
970-1000	80,000	1 cell replaced	13C
			$3,600

[a]Battery cost to consumer taken as $150/kWh.
Cell cost at $30/cell and labor at $50/hr.

string. These tests showed that the voltage behavior of a failed cell passed through a voltage maximum of -1.6 V during discharge and then stabilized at -0.4 V. The conclusion drawn from the single-cell work was that the operation of a module with a small percentage of failed cells might be feasible if provisions for the excess heat removal from failed cells were made in the design of the thermal management system.

5. An analysis of battery life that was based upon a hypothetical cell population that had a MTTF of 1500 cycles, a Weibull slope of 5, and a capacity loss rate of 2%/100 cycles was made. The analysis suggests that a battery lifetime of 1000 cycles is achievable with a replacement of 5 cells.

APPENDIX G

PERFORMANCE AND COST PROJECTIONS FOR LITHIUM-IRON SULFIDE BATTERIES

Prepared for

Jet Propulsion Laboratories
4800 Oak Grove Drive
Pasadena, CA 91109

Contract No.: 956761

Subject: Performance and Cost Projections
for Lithium-Iron Sulfide Batteries

Prepared by

Gould Research Center
Materials and Devices Laboratory
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Rolling Meadows, Illinois 60008

Date: March 1984

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I. INTRODUCTION

This report has been prepared under JPL Contract No. 956761 in support of the Jet Propulsion Laboratory Electric and Hybrid Vehicle Project.

Research and development on lithium alloy-metal sulfide, molten salt electrolyte rechargeable batteries has been ongoing at Gould since the mid-1970s until the present time. This effort was initially supported by DOE contracts via the National Laboratories (ANL, SNL, LBL) and more recently by contracts from the Air Force and EPRI in addition to funds from Gould.

The lithium-sulfur system is generic in nature, in that there are a number of choices possible for both the negative and positive electrode active materials. The most energetic electrochemical couple would be that of elemental lithium and elemental sulfur. However, since both these electrodes would be molten at the battery operating temperature, it is extremely difficult to engineer a practical cell design. Consequently the technology has evolved by sacrificing some of the specific energy offered by the elemental lithium and sulfur electrodes and employing lithium-alloy negative electrodes and metal-sulfide positive electrodes. These latter type electrodes permit practical engineering cells to be built since the electrodes are solid at the cell operating temperatures of 350-475°C; the melting point of the salt electrolyte dictates the operating temperature range. The lithium alloys which have received greatest attention are lithium-aluminum (e.g. 20 w/o Li:80 w/o Al) and lithium-silicon (e.g. 43 w/o Li:57 w/o Si); each of which offers particular advantages in terms of properties and cell performance. Most of the early engineering cell development was performed with Li-Al negative electrodes, however, more recently the Gould development effort has chosen to use a physical mixture of the two binary alloys Li-Al and Li-Si in order to take advantage of the characteristics of each alloy.

Similarly, there are a number of possible alternatives that can be considered for the positive electrode from the metal chalcogenides. In particular, the sulfides of iron have received the greatest attention since they are plentiful and hence relatively inexpensive. Although iron disulfide is more energetic

than the monosulfide it has not been considered in this study since its use necessitates the employment of relatively exotic and therefore expensive materials (e.g., molybdenum) for the positive electrode current collection system. The cost of such a current collection system is prohibitive to be considered in the near term for the electric vehicle application. Consequently for this study iron monosulfide (FeS) has been considered exclusively since the material is inexpensive and can readily be incorporated into practical cell designs in the time-frame relevant to this study re-early 1990s.

To date, the Li-MS work at Gould has been devoted primarily to cell development, rather than the complete battery system and therefore, we have limited knowledge to fully address all aspects of the battery system design. However, this report has been prepared in close collaboration with fellow Li-MS developers at ANL and it is the intention of the Gould report to corroborate the ANL projections where possible by experimental data and relevant studies performed at Gould under various contracts.

II. PERFORMANCE MODELING

In performing this study, two basic cell configurations have been considered. These are a conventional monopolar prismatic cell design, in which electrodes of the same polarity are connected in parallel within the cell and a bipolar configuration in which the electrode elements are stacked in series. The monopolar prismatic design is the current "state-of-the-art" which has been developed extensively during the DOE programs at ANL, Gould and Eagle Picher and is currently being pursued for a 9-cell battery demonstration in the EPRI van battery program. With minor improvements to existing technology this prismatic design is well capable of meeting the commuter car and van requirements (see Table 1).

The bipolar design which is currently being developed at Gould and the Admiralty Materials Technology Establishment (AMTE) in the UK, has the potential for significant performance improvement over the monopolar design particularly in terms of power and energy density since the current path

within the electrodes is significantly reduced and the current collection system is greatly simplified with a concomitant reduction in weight. Hence, a bipolar design is desirable for the hybrid and full performance EV where high power and high energy densities are required respectively (see Table 1).

The specific energy and peak power projections for the Li alloy - FeS system, for the various classes of batteries in Table 1, are given in Tables 2 and 3 respectively.

For the prismatic-monopolar cell, calculations have been based on a seven plate design, (i.e. 3 positive electrodes and 4 negative electrodes). The negative and positive electrodes are pressed plaques of a 80 w/o LiAl-20 w/o LiSi mixture and iron monosulfide (FeS) respectively. The separator is a high surface area magnesium oxide powder. Each of these three components also contain the alkali-halide salt electrolyte. The prismatic design has been selected for the commuter car and van applications since the performance requirements for these can be met with minor improvements in the current technology.

The bipolar design was selected for the full-performance EV and the hybrid vehicle since such a design offers the best promise of achieving the high energy and power densities required in these applications.

The methodology used in projecting the performance of the monopolar and bipolar batteries are discussed in Appendices A and B respectively.

Table 1

Battery Energy and Power Requirements for Electric and Hybrid Vehicles

Vehicle Type	Total kWh	Specific Energy Battery Wh/kg	Specific Energy Vehicle Wh/kg	Total kW	Peak Power Battery W/kg	Peak Power Vehicle W/kg	Power: Energy Ratio
Commuter	12	67	12	25	140	25	2.08
General Purpose EV or Commercial Van	25	50	12	60	120	25	2.40
Hybrid	15	50	9	50	167	30	3.33
Full-Performance EV	50	155	30	50	155	30	1.0

Table 2 Specific Energy with Discharge Rate for Li Alloy-FeS Batteries

Class	Battery Designation	Battery Design	Battery Specific Energy (Wh/kg)* at Various Discharge Rates (W/kg)				
			20	60	80	100	200
1	Present	Monopolar	54	43	40	37	0
2	Commuter & 3/4 Ton Van	Monopolar	74	62	56	54	0
3	Full-Performance	Bipolar	116	94	85	76	32
4	Hybrid	Bipolar	108	88	79	71	30

* The battery specific energy has been calculated by derating the cell specific energy by 25-30%.

Table 3 Peak Power at Various States of Charge for Li Alloy-FeS Batteries

Class	Battery Designation	Battery Design	30 Sec Power Capability (W/kg) at Various States of Charge			
			80%	50%	30%	10%
1	Present	Monopolar	155	125	95	45
2	Commuter & 3/4 Ton Van	Monopolar	200	165	125	60
3	Full-Performance	Bipolar	272	233	188	129
4	Hybrid	Bipolar	254	217	175	120

III. COST PROJECTIONS

The projected OEM price for lithium alloy-iron monosulfide batteries for the different classes of vehicles is shown in Table 4.

The basis for these cost projections is given in Appendix C.

IV. TECHNICAL SUPPORT FOR PROJECTIONS

The main departures from the state-of-the-art technology that were considered in making the performance and cost projections were as follows:

(i) A bipolar battery design was chosen for the hybrid and full-performance electric vehicles since this has the potential for the high-power and high-energy outputs required by these classes of vehicle.

The feasibility of success of a bipolar design depends on eliminating stray conductive paths, both electronic and ionic, between the cells in the battery stack which would otherwise allow shunt currents to discharge the stack. One of the main sources for these stray conductive paths is electrolyte bridging between cells and to the battery case. However, the immobilized electrolyte-powder separator concept being developed at Gould and AMTE in the UK is an approach which could lead to a solution to this problem and therefore greatly simplify the design of peripheral seals required to isolate cells in the stack. Initial tests on bipolar stacks at Gould have produced very promising results and this work is to be pursued under our present EPRI contract.

The other advantage of a bipolar design is that the current collection system is less complex than a monopolar design, and therefore the part count, weight and cost are all reduced.

(ii) The materials considered in the costing of both the monopolar and bipolar batteries are those presently used in the Gould technology. However, some cost reductions could be readily brought about by

Table 4 Projected Cost of Lithium-Metal Sulfide Batteries

Battery Designation	Battery Design	Energy kWh	Power kW	P/E	Materials	OEM Selling Price $/kWh	OEM Selling Price $/Battery
Present	Monopolar				LiAl-FeS; MgO; LiCl-KCl LiAl: LiSi-FeS; MgO; LiCl-LiF-LiBr		
Commuter	Monopolar	12	25	2.08	LiAl: LiSi-FeS; MgO; LiCl-LiF-LiBr	154	1848
Gen. Purpose EV or Commercial Van	Monopolar	25	60	2.40	LiAl: LiSi-FeS; MgO; LiCl-LiF-LiBr	154	3850
Hybrid	Bipolar	15	50	3.33	LiAl: LiSi-FeS; MgO; LiCl-LiF-LiBr	127	1905
Full-Performance EV	Bipolar	50	50	1.0	LiAl: LiSi-FeS; MgO; LiCl-LiF-LiBr	127	6350

utilising less expensive materials if one is willing to accept some modest loss in performance in either specific energy and/or power.

The cell and electrode containment hardware and the current collection system which are currently fabricated from stainless steel and nickel respectively could be made from a low carbon steel. The consequence of such a change would be a heavier cell (i.e. lower specific energy) if the strength of the containment hardware at the battery operating temperature and the conductivity of the current collection system are to be maintained. Alternatively, some relaxation in the conductivity of the current collection system would probably result in a cell with reduced power capabilities especially at low states of charge. The life of the battery may be affected also if less expensive alloys are chosen for the hardware since their corrosion resistance is more than likely to be inferior at the elevated operating temperatures, (i.e. 450-500°C). Similarly, the selection of the negative active material may govern the choice of alloy for the hardware, especially the current collector.

From the cost analysis summarized in Appendix C however, it can be seen that the cost of the lithium bearing compounds are a major portion of the battery cost (i.e. ~40%). If a significant reduction is to be made therefore in the cost of lithium-metal sulfide batteries it is in this area which the greatest savings could be realized.

The two obvious ways in which the lithium bearing material cost can be reduced are;

i) Reduce the quantity of lithium bearing compounds or replace with cheaper alternatives.

ii) Identify a low cost source of lithium and develop inexpensive manufacturing processes to produce the required lithium compounds.

Examples of these would be to build cells which are negative electrode limited and starved in electrolyte. In addition a change in electrolyte composition

from the ternary lithium halide salt to the binary LiCl-KCl electrolyte would significantly reduce the electrolyte cost since lithium bromide is the major constituent in the ternary salt electrolyte.

A low cost source of lithium is lithium carbonate which is currently available as an item of commerce. The conversion of lithium carbonate into other lithium compounds suitable for building lithium-metal sulfide batteries has been explored to some depth by Chilenskas et al at ANL. I refer you to their report[1] and analysis in which they have shown the potential for reducing the cost of lithium-iron sulfide batteries below the $154-127/kWh range projected in this report.

V. ENERGY BALANCE

An energy balance for a vehicle operating on a JPL modified FUD schedule (see Figure 1) has been developed based on data from JPL and the following assumptions;

1) Vehicle test weight 1660 kg.
2) Battery weight 488 kg.
3) Average speed for cycle 3, 46x5/8x60/88=19.6 mph.
4) Time for cycle 3, 436/3600=0.121 h.
5) Distance covered in cycle 3, 19.6x0.121=2.37 miles.
6) Total distance per day 12x2.37=28.4 miles.
7) Battery heat loss at operating temperature = 150 W.
8) Charger efficiency 85% (D.C. out/A.C. in).
9) Battery efficiency 80% (D.C. out/D.C. in).
10) Battery Heat Capacity 0.25 Wh/kg °C.
11) Battery Specific Energy 75 Wh/kg.

An energy balance diagram is shown in figure 2 for performing the JPL/FUD driving schedule over a period of 24 hours. Each of the major components in the system are identified along with the input/output energy.

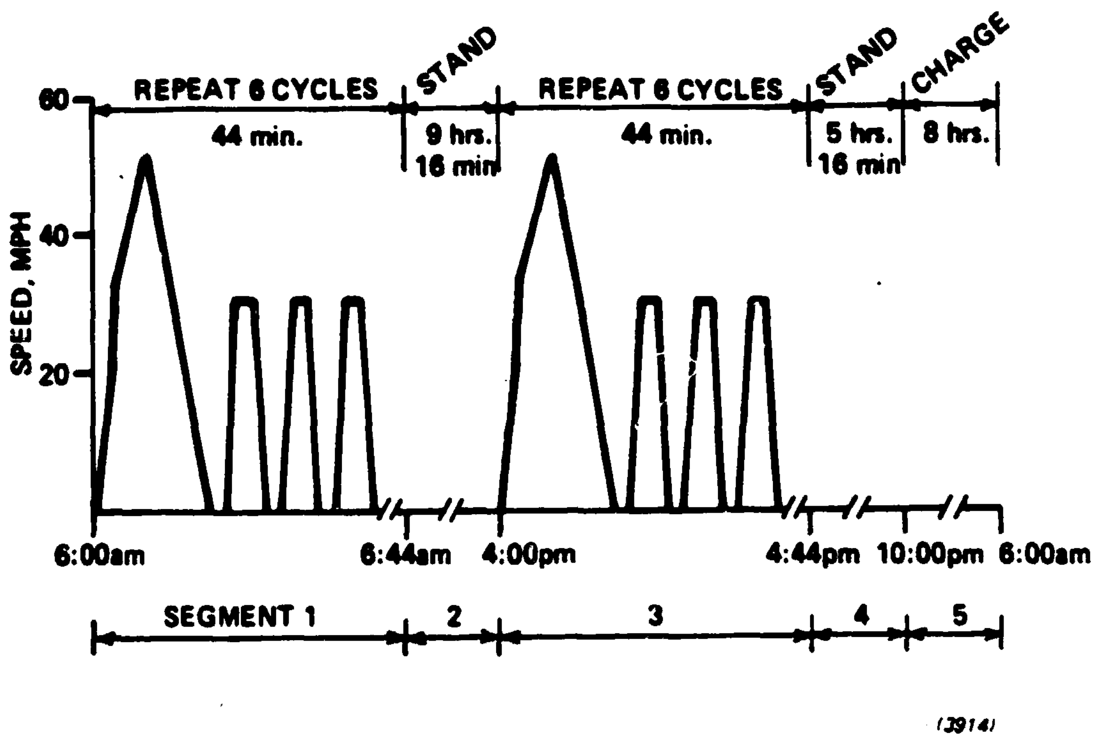
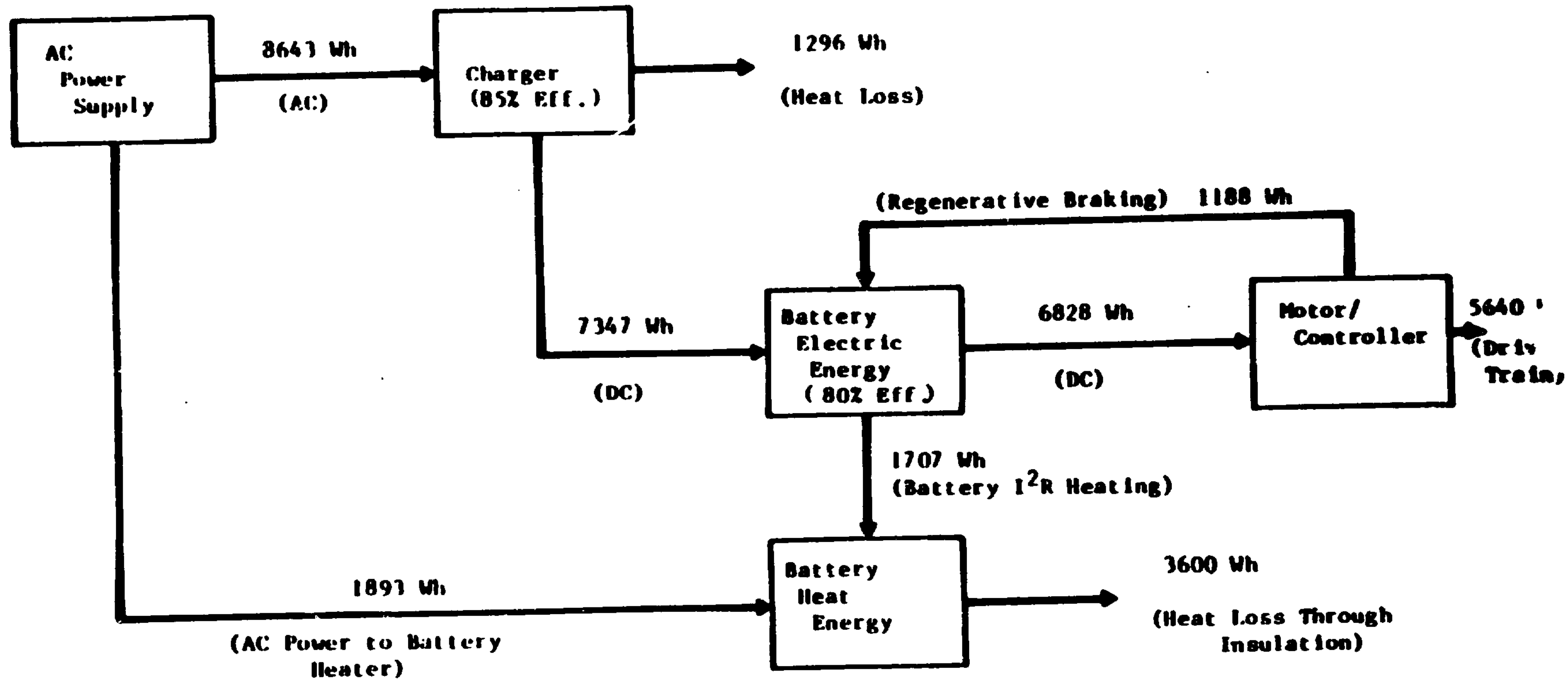


Figure 1 JPL modified Federal Urban Driving Schedule for 24 hour period.

Figure 2

Energy Balance Over 24 Hours for JPL/FUD Schedule



A summary of the overall energy consumption and efficiency coefficients are given in Table 5 while estimates for the in-use energy consumption are given in Table 6.

Table 5 Energy Consumption Summary

Battery heat loss per 24h.	3600 Wh
Battery I^2R heating during operation over 24h	1707 Wh
External heating required to maintain battery temperature over 24h.	1893 Wh
Total A.C. Energy Required	363 Wh/mile
Battery D.C. Output	235 Wh/mile
Vehicle Energy Consumption	142 Wh/tonne mile
Overall Energy Efficiency	65%
Battery heat energy generated during segment 1 of JPL/FUD cycle.	854 Wh
Maximum temperature rise of battery during segment 1 of JPL/FUD cycle.	7°C
Energy required to raise battery temperature from R.T. to 450°C.	53 kWh
Total Battery Energy	36.6 kWh
Depth of Discharge to drive JPL/FUD cycle	19%

Table 6 Estimates of In-Use Energy Consumption

Parameters	Segments 1	2	3	4	5
Start up and Shut down	None required: Battery capable of maintaining its operating temperature				
Self-Discharge (Wh)	22	278	22	158	240
Shunt Current	------------------none---------------------				
Parasitics	------------------none---------------------				
Thermal Loss (Wh)	110	1390	110	790	1200
Charge Eff. (Battery AC in /DC out					79%

VI. LIFE CONSIDERATIONS

A. Cycle Life

The cycle life of Gould engineering-size cells (i.e. theoretical capacity based on the positive electrode in the range of 120-240 Ah) is currently around 500 cycles with a number of cells having exceeded 800 cycles. The prospects for achieving 1000 cycles mean-time-to-failure (MTTF) therefore in the next few years is reasonably high.

Gould has limited experience in testing small battery modules (i.e. 3 to 10 cells connected in a series string), however results from this work indicate that generally one would expect similiar lifetimes from modules as from individual cells provided that the series string of cells is periodically balanced. The current status of cycle life for engineering size cells is discussed in Appendix D.

B. Life Effects

The degradation in specific energy with cycling has been progressively reduced during the development of lithium alloy-iron monosulfide cells from approximately 0.07% per cycle to 0.02% per cycle for cells discharged at the C/3 rate. Data generated under the Air Force contract indicates that the degradation in specific energy with cycling is dependent on the discharge rate and the depth of discharge. As would be expected the higher the discharge rate or greater the depth of discharge the faster is the decline in specific energy with cycling.

The coulombic efficiency of new cells after formation can be as high as 99%, however, this can be somewhat lower (<4%) depending on the overall charge-discharge cycle time since the cells have a finite leakage current in the range of 150-300mA. With cycling there is a very gradual decline in coulombic efficiency until the point of cell failure when it drops dramatically.

In small battery module tests, cells which have developed a partial short have been found to contribute to the battery capacity for a portion of the discharge cycle.

The thermal characteristics of cells during operation over many cycles has not been thoroughly investigated. However, from the extensive number of cell tests performed there is little evidence of a substantial change in the cell charge-discharge temperature profile with cycling. The largest increases in cell temperature above the normal operating temperature of ~450°C occur when cells are discharged at very high rates (e.g. ~3C), in such cases cell temperatures have been observed in excess of 520°C at the end of discharge.

C) Failure Modes

As indicated in the previous two sections the main failure modes identified for lithium alloy-iron monosulfide cells are i) loss in capacity and ii) decrease in coulombic efficiency. Initially, loss in capacity was the predominant mode of failure but the most recent series of cell tests indicate that the decline in coulombic efficiency is now the primary failure mode. The mechanism by which the decline in coulombic efficiency occurs has not yet been elucidated, other than that it is attributed to the development of a conductive path or paths between the electrodes. Metallographic examination, performed by J. Battles of ANL, on some earlier Gould cells indicate that the conductive paths are due to the deposition of iron within the powder separator layer and positive active material exudation, however there have been a number of changes in the more recent Gould cells and these have not yet been examined.

VII. OTHER OPERATIONAL CHARACTERISTICS

A. Special Charge Requirements

The normal charge and discharge reactions in lithium alloy-iron monosulfide cells result in the formation of solid products without gaseous side reactions. This permits the cells to be hermetically sealed and eliminates the need for electrolyte additions.

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Gould Research Center
Materials & Devices Laboratory
March 12, 1984

Information on the effects of overcharging and overdischarging Li alloy-FeS cells has been obtained from thermodynamic data, cell tests and metallographic examination of cells after cycling.

The upper cut-off voltage on charge normally used for LiAl-FeS cells is 1.55 V (IR-included) and 1.65 V for LiAl:LiSi-FeS cells. When these upper charge cut-off voltages are exceeded, the first major overcharge reaction which occurs at approximately 1.8 V (IR-free) is as follows:

$$Fe + 2LiCl + 2Al \rightarrow FeCl_2 + 2LiAl$$

This reaction involves any free iron in the FeS electrode to form $FeCl_2$ and the deposition of additional lithium in negative electrode. On extended overcharge the $FeCl_2$ can leave the positive electrode and permeate the separator where it is reduced to iron and thus cause a short. In the case of the negative electrode the lithium concentration can become sufficiently high that it forms a liquid metal phase in the electrode which can also ultimately lead to a short.

The normal lower cut-off voltage on discharge for Li alloy-FeS cells is in the range 1.0-0.9 volts (IR-included). The principal overdischarge reaction is;

$$Al + 3LiCl \rightarrow AlCl_3 + Li$$

which occurs at -1.5 V (IR-free). In this case, aluminum in the negative electrode is oxidized to form $AlCl_3$, which is soluble in the electrolyte, and metallic lithium is deposited on the positive electrode. The cell under these conditions is in a state of reversal. If discharging is continued then the cell eventually short circuits due to the deposition of metallic aluminum in the separator or the formation of liquid lithium at the iron sulfide electrode.

Experience has shown that cells are much more forgiving after being subjected to overdischarge than to overcharge. Indeed a number of cells which have been driven into reversal have fully recovered their initial capacity after being

subjected to a slow rate charge. In the case of severely overcharged cells no recovery has been possible.

In order to maintain the full capacity of the Li alloy-FeS battery during operation it will be necessary to periodically equalize the individual cells in the battery. The imbalance in the battery is brought about by the small variation in coulombic efficiency of the cells. Tests at Gould on 10-cell series-string batteries have shown that it takes a number of cycles before a significant amount of capacity is unavailable due to imbalance in the cells and therefore it is anticipated that the equalization charging would be required at most on a weekly basis. This suggests that fleet vehicles could be operated with an inexpensive battery charger dedicated to each vehicle for most of the overnight charging and that one more expensive charger-equalizer unit could be rotated among a minimum of seven vehicles. Concepts for charging and equalization of Li alloy-FeS batteries are under investigation by ANL in the EPRI program.

It is anticipated that periodic complete discharge will not be necessary for Li alloy-FeS batteries.

B. Maintenance Requirements

Regular maintenance, other than a periodic charge and equalization, will not be required for a Li alloy-FeS battery since the cells are sealed; therefore no electrolyte addition is necessary. The cell equalization can be readily accomplished overnight.

The operating temperature range of the battery will be controlled automatically by a sophisticated thermal management system which is capable of heating and cooling the battery on demand. It is envisaged that a separate AC circuit will be incorporated into the charging units to provide power to the resistive battery heaters. This arrangement will maintain the battery temperature during charging or for periods of intermediate standing. For longer term storage and major overhaul, the battery can be cooled to room temperature and then brought back into service by reheating to operating

temperature. The advantage in overhauling the battery at room temperature is that it will be electrically safe which is not the case with ambient temperature battery systems.

An electric vehicle battery will comprise a number of multi-cell submodule units. Hence, one refurbishment scenario would be to replace the complete submodules in which there are failed cells by either new or reconditioned submodules. The submodules removed from the battery could then be dismantled and rebuilt with the appropriate number of new cells for a future refurbishment of the battery. Replacement of a few cells (<10% of total number in battery) would no doubt be more cost effective than replacing the complete battery and should extend the life of the battery substantially (see ANL Analysis in Appendix D of their report).

VIII. PACKAGING FLEXIBILITY

A. Volumetric Considerations

At Gould we have not yet designed a full-size EV battery for a specific application and therefore can only address the volumetric requirements of a battery in general terms. There are, however, a number of design criteria which have to be satisfied in order to maximize the volumetric energy density of the battery, these are:

i) Minimize the battery surface area: volume ratio and thus minimize the heat losses. Obviously a battery in the form of a cube would best satisfy this condition, but vehicle design usually dictates that the length of the battery is at least a factor of two greater than the width or the height.

ii) The insulated battery enclosure need only be large enough to hold the desired number of battery submodules, the intermodule connectors, charge control wires and the heat exchanger system which will heat and cool the battery to maintain the desired operating temperature range.

iii) The wall thickness of the insulative enclosure should be as thin as possible. However, the thickness depends on the thermal conductivity value of the insulation and the heat loss which is tolerable in order to operate the battery. The lowest conductivity insulation is the most expensive and hence there is an economic trade-off to be considered between the various types of insulation available.

In order to obtain an approximate range for the volumetric energy density of Li alloy-FeS batteries the following assumptions have been made:

(i) Density of Li alloy-FeS cells ~2 g/cm^3 (kg/ℓ)

(ii) Wall thickness of insulative enclosure ~2.5 cm

(iii) Thickness of insulative end plug ~7.5 cm

(iv) Heat exchanger occupies ~15% of insulative enclosure

(v) From assumptions (i)-(iv) density of battery (including enclosure) ~1.3 g/cm^3 (kg/ℓ)

(vi) Volumetric energy density (Wh/ℓ) = Gravimetric energy density (Wh/kg) x density (kg/ℓ)

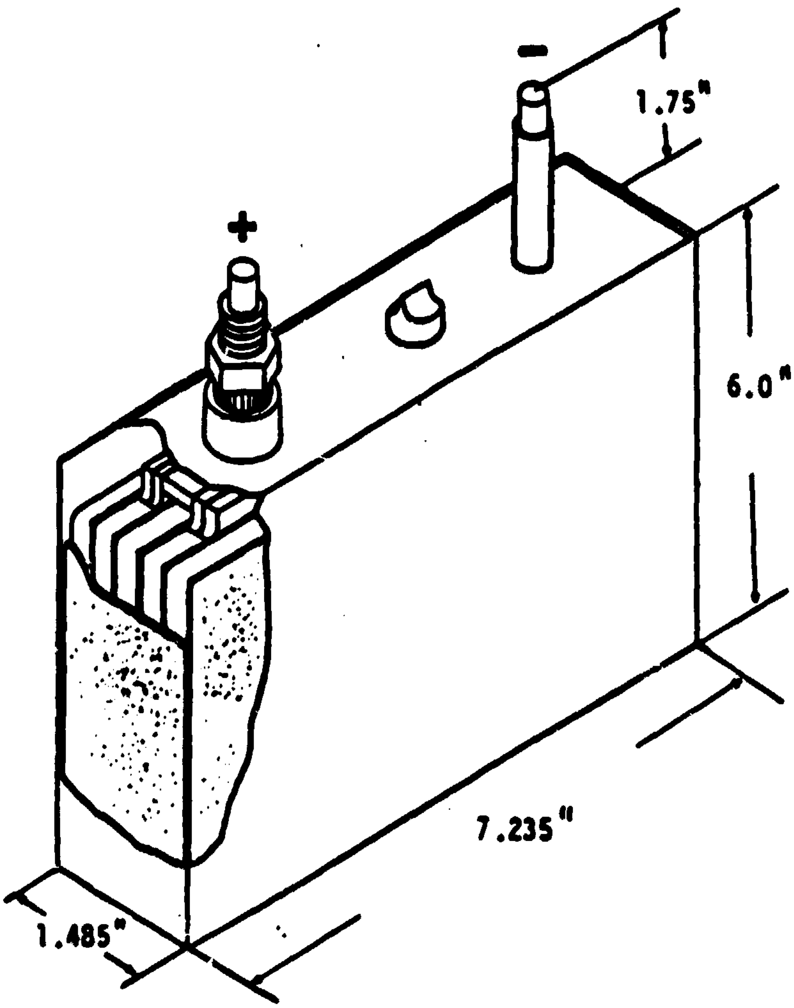
Hence from the cell and battery densities plus the gravimetric energy density values calculated in Appendix A and tabulated in Table 2 a range of volumetric energy densities can be derived which range from 1.3 to 2 times the gravimetric energy density. It should be noted that the smaller the battery size in terms of capacity (kWh), the greater will be the volume fraction of the insulative enclosure, and hence the volumetric energy density will be lower the smaller battery size even though identical battery submodules can be used in different size batteries.

B. Size Limitations

The Li alloy-FeS electrochemical system permits great flexibility in the design of both monopolar-prismatic cells and bipolar batteries. In the development of the system a number of different electrode sizes have been used in engineering cells from 7.5 cm x 12.5 cm to as large as 30 cm x 30 cm. The choice of electrode size, thickness and number will greatly depend upon the battery requirements in terms of power and energy. In general the high power battery would comprise many small, thin electrodes whereas the high energy battery would comprise few, large, thick electrodes. However, it is usually necessary to make compromises in both power and energy to obtain optimum battery performance. The larger electrode designs tend to have non-uniform current distribution on the electrodes which result in reduced active material utilization and increased thermal problems, consequently an electrode size of ~200 cm^2 is presently being considered for the EV application. A typical EV monopolar cell design is shown in Figure 3. The one feature of the design which permits a significant reduction in the cell volume is the height of the terminals, particularly the positive, above the main body of the cell. A substantial portion of the positive terminal length is devoted to the feedthrough seal which electrically isolates the terminal from the cell container. Hence if a low profile ceramic-to-metal seal is developed for the positive feedthrough then the length of the terminals could be significantly reduced with the consequential improvement in volumetric energy density.

C. Special Considerations

The complete Li alloy-FeS battery comprises a high-efficiency insulating enclosure, a heating and cooling system, current, voltage and temperature leads and control instrumentation packaged as an integral self-contained unit. The cooling media will be circulated to the heat exchanger by a small electric fan mounted adjacent to the battery.



Theoretical Capacity: 240 Ah
Cell Weight: 2.5 kg
Volume: 1.36 ℓ

Figure 3 Lithium-Metal Sulfide Cell

D. Scale Effects

Detailed scaling factors have not yet been derived for batteries in the range of 10-50 kWh. However, since the Li alloy-FeS system permits great flexibility in design parameters (i.e. size, thickness and number of electrodes) it should be possible to develop high performance batteries over the range of interest.

Batteries of a monopolar prismatic design will be used first to demonstrate the feasibility of high temperature lithium-metal sulfide batteries in electric vehicles, but the ultimate performance of the system in this application will be realized in a bipolar battery design.

ACKNOWLEDGEMENT

This report was prepared in support of the Jet Propulsion Laboratory Electric and Hybrid Vehicle Project, under Contract No. 956761 and in collaboration with fellow Li-MS battery developers at Argonne National Laboratory who have also written a similar report for the JPL Project.

References

1) Chilenskas and Shimotake "Performance/Cost Projections for Lithium/Iron Sulfide Batteries". Report prepared for JPL under Electric & Hybrid Vehicle Program.

Appendix A

PRISMATIC-MONOPOLAR BATTERY PERFORMANCE PROJECTIONS

I. Specific Energy

The current technology data presented in Table 2 has been generated from recent tests on prismatic-monopolar-multiplate cells which have a theoretical capacity of ~240 Ah and a height:width aspect ratio of ~0.7. This particular cell design has evolved over several years during a DOE contract with ANL and more recently a contract with the Air Force. The cell developed for the Air Force had a theoretical capacity of ~120 Ah and an aspect ratio of ~0.7. However, many of the design features employed in the Air Force cell have now been incorporated into a larger capacity cell (i.e. 240 Ah) for an electric van application under our current contract with EPRI.

Battery specific energy data at various discharge rates are plotted in Figure A-1. These plots have been obtained by derating the cell specific energy data by 25%. This is an average derating factor one might expect when the weight of all the ancillary battery hardware and thermal management system are accounted for in a high temperature battery design.

The 'projected' performance of a monopolar battery also shown in Figure A-1 has been derived from a second iteration of the cell design currently being evaluated under the EPRI program. By optimizing the first design it has been possible to significantly reduce the weight of the cell, particularly the hardware, without making any change to the quantity of electrochemically active materials. Hence it is projected that this cell will exhibit a significant improvement in performance. The projected cell performance, again has been derated by 25% in order to obtain the battery specific energy.

II. Peak Power

The peak power data for the current technology and the 'projected' prismatic-monopolar battery are plotted in Figure A-2. The current technology data are

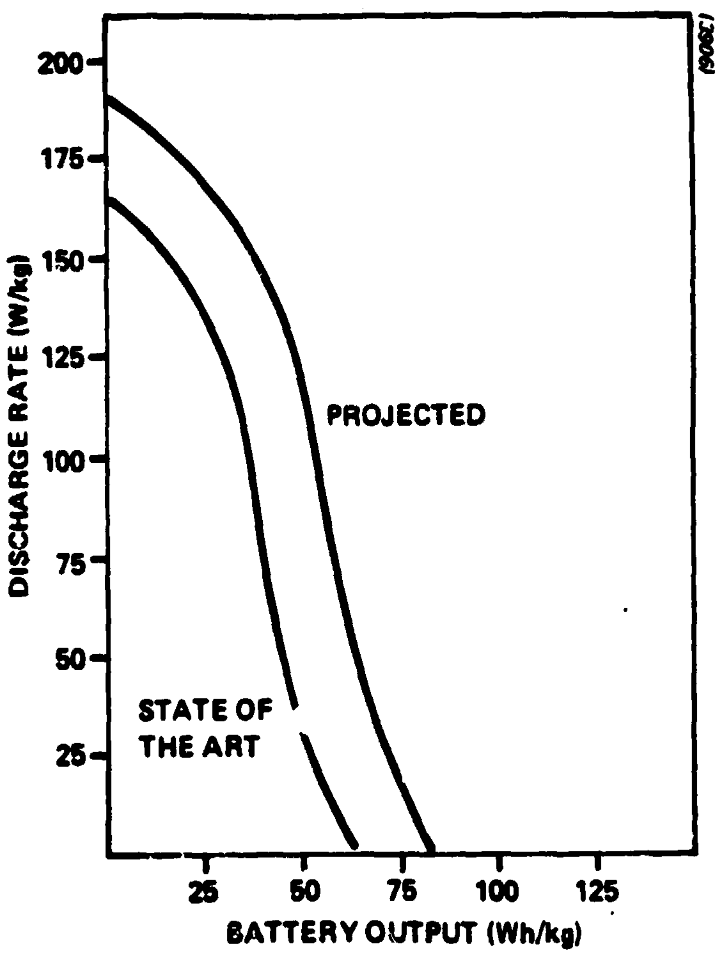


Figure A-1 Specific energy of a prismatic monopolar lithium alloy-iron sulfide battery as a function of constant power discharges.

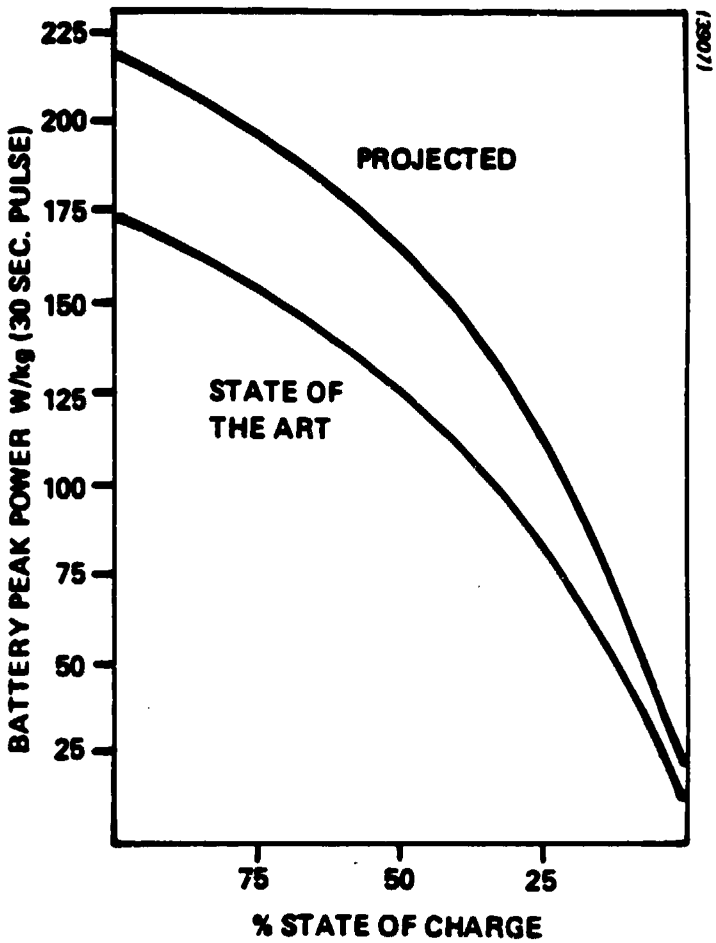


Figure A-2 Peak power (30sec pulse) of prismatic monopolar lithium-iron sulfide batteries at various states of charge.

experimental results from the same cells as were used for the specific energy measurements. The "projected" data was generated from the second iteration cell design mentioned previously. All cell data was derated by 25% in order to estimate the battery peak power performance.

Appendix B

BIPOLAR BATTERY PERFORMANCE PROJECTIONS

An analysis has been performed in order to project the performance that could be expected from a bipolar type lithium-iron monosulfide battery which utilizes the immobilized electrolyte-powder separator concept that Gould has been actively pursuing since 1980. This preliminary analysis has been limited to projecting:

i) The specific energy profile of a battery discharged at constant power in the range 20-200 W/kg.

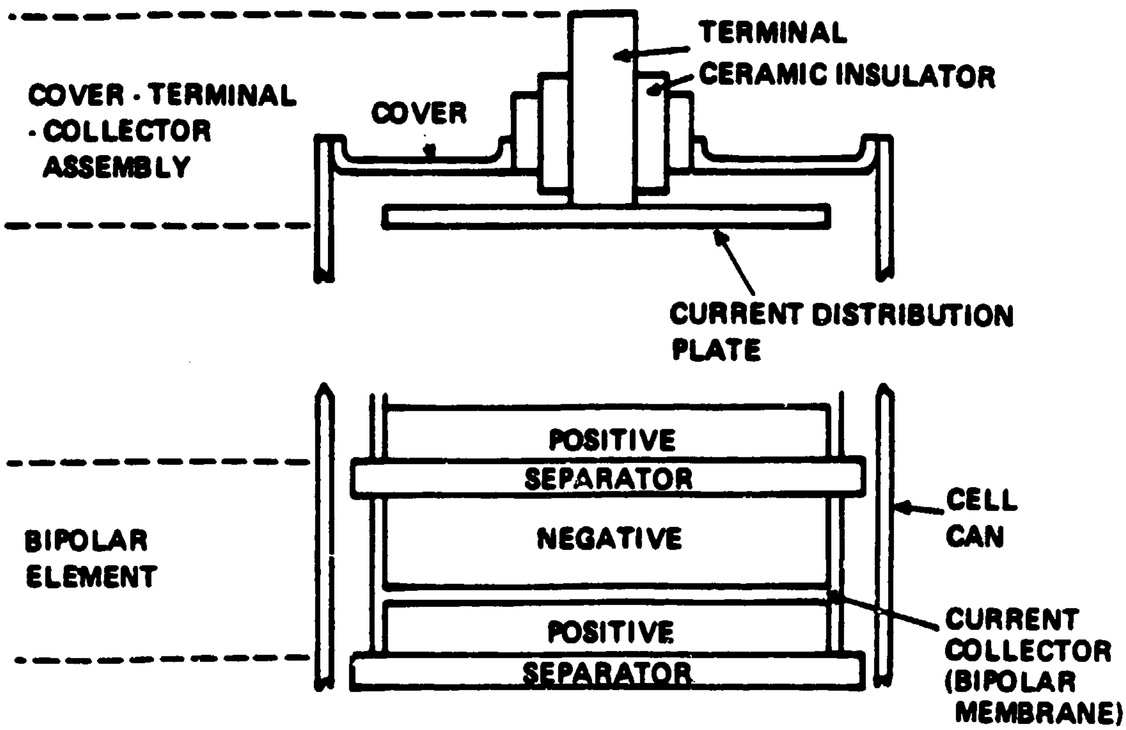
ii) The peak power performance of the battery as a function of the state-of-charge as defined for a nominal C/3 discharge rate.

I. The Bipolar Design

The electrochemical couple proposed in the bipolar design is the same as that employed in the prismatic-monopolar design. This is a LiAl:LiSi alloy negative electrode and an iron monosulfide positive electrode operated in a ternary lithium halide electrolyte (Li:Br, F, Cl) in the temperature range of 450-500°C. The separator is also the magnesium oxide powder type.

A conceptual design of the proposed bipolar battery is shown in Figure B-1. The basic components of the battery are the bipolar element, the current collector-terminal-feedthrough system and the container for the stack. The bipolar element comprises one positive and one negative electrode placed either side of a thin metal current collector membrane. In addition a separator layer has been included in the bipolar element in order to simplify the battery calculations. The battery is assembled by stacking the required number of bipolar elements in order to obtain the desired battery energy.

The advantages offered by a bipolar design over that of a monopolar design are:



n = NO. OF BIPOLAR ELEMENTS
C = CAPACITY OF POSITIVE ELECTRODE (Ah)
U = UTILIZATION OF POSITIVE ACTIVE MATERIAL
W_1 = WEIGHT OF BIPOLAR ELEMENT
W_2 = WEIGHT OF COVER-TERMINAL-DISTRIBUTOR ASSEMBLY
V = CELL VOLTAGE OF BIPOLAR ELEMENT (VOLTS)

$$\text{SPECIFIC ENERGY (Wh/kg)} = \frac{(n+1)\,CVU}{(n+1)\,W_1 + 2W_2}$$

(3808)

Figure B-1 Bipolar cell stack design

i) The weight of the current collection system can be considerably reduced since the current path is perpendicular to the face of the electrodes, i.e., bus bars and distribution plates necessary in a monopolar design can be eliminated.

ii) A more uniform current distribution can be obtained on the electrodes and therefore the active material utilization is improved particularly at the higher rates of discharge.

II. Methodology for Bipolar Design Calculations

The first step in designing the conceptual bipolar battery proposed in Figure B-1 is to assign physical and electrochemical parameters to the various components in the battery. The values assigned to these parameters are based on data that has been obtained from engineering and experimental pellet cells. The facial area of the electrodes has been maintained the same as in the prismatic-monopolar design (i.e. ~214 cm^2) so that the performance between the two batteries can be directly compared. However, for the bipolar battery we have opted for a circular electrode instead of a rectangular electrode.

From these key parameters and empirical relationships that have been derived for utilization, voltage against current density and depth of discharge for the Li-MS system it is possible to calculate the specific energy and sustained power. The parameters assigned to the various components are listed in Table B-1.

In order to calculate the available energy from the battery at various discharge rates it is necessary to know the relationship between active material utilization and current density. The following, empirical equation has been derived from experimental data on advanced cell work performed both at ANL[1] and Gould[2].

---

1. ANL-80-128 Report, p. 46 (1981).
2. S. Misra private communication.

Table B-1

Bipolar Battery Design Parameters

Electrode Diameter	16.51 cm
Electrode Area	214.08 cm^2
No. of Bipolar Elements	24
Theoretical Capacity of Positive Electrode	40.78 Ah
Positive Plaque Loading Density	1.5 Ah/cm^3
	0.45 Ah/g
Negative Plaque Loading Density	1.0 Ah/cm^3
	0.63 Ah/g
Separator Density	2.35 g/cm^3
Negative:Positive Capacity Ratio	1.3:1
Positive Electrode Thickness	0.127 cm
Negative Electrode Thickness	0.248 cm
Separator Thickness	0.152 cm
Bipolar Membrane Thickness	0.008 cm
Weight of Bipolar Element	300 g
Weight of Terminal/Collector/Battery End Cover	300 g
Total Battery Weight	8.1 kg
Total Battery Volume	4.27 liters

$$\text{Utilization (\%)} = (1 - 1.67\ i) \times 100$$

where i is current density in A/cm^2. This equation has been plotted in Figure B-2. Another factor which affects the utilization of an electrode is the thickness (i.e. the thicker the electrode the poorer the utilization). However for electrodes with a thickness of <0.15 cm the variation in utilization with thickness in insignificant and therefore, since we have chosen for this analysis a positive electrode thickness of 0.127 cm, we have ignored this effect.

The average voltage on discharge for a Li alloy-FeS cell as a function of the discharge rate has been integrated from experimental data measured on a pellet cell, since this type of cell closely approximates to the electrode arrangement in a bipolar stack. This data, plotted in Figure B-3, shows the average discharge voltage as a function of current density for a single cell. The bipolar battery voltage is assumed to be n+1 times the single cell voltage, where n is the number of bipolar units in the battery. Hence the battery energy and sustained power can be calculated by multiplying the average bipolar stack voltage by the cell capacity and average discharge current, respectively. The specific energy versus discharge rate is plotted in Figure B-4 for the bipolar battery, including a derating factor of 25% to take into account all other ancillary hardware.

In order to calculate the peak power for the bipolar battery it is necessary to know the peak power flux, W/cm^2. Again, such data are available from 30 sec. peak power pulse tests performed on advanced design pellet cells and higher power prismatic cells with lithium alloy and iron monosulfide electrodes. The peak power flux data are plotted in Figure B-5 as a function of state-of-charge for both state-of-the-art and advanced design cells. The 30. sec peak power for the bipolar battery was then calculated by multiplying the flux values by the area of electrode in the battery. These values were derated by a multiplying factor of 0.75 to compensate for the ancillary battery hardware. The results of these computations are presented in Table B-2 which are the 30 sec. specific peak power capability at various states-of-charge for the complete battery.

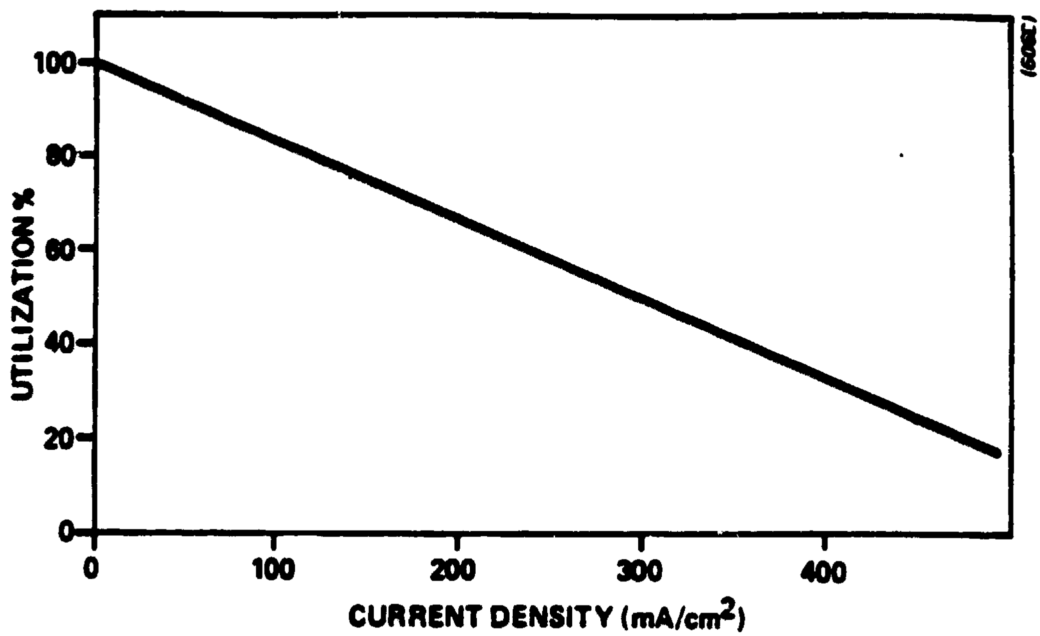


Figure B-2 Positive electrode utilization as a function of current density for lithium alloy-iron monosulfide cells.

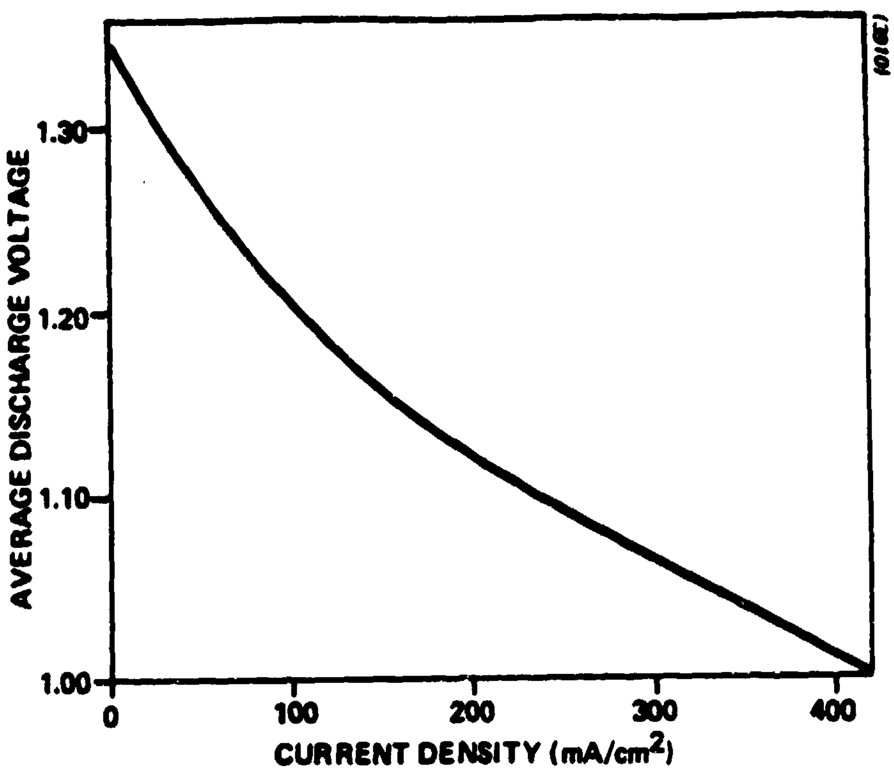


Figure B-3 Average discharge voltage for a lithium alloy-iron sulfide cell as a function of current density.

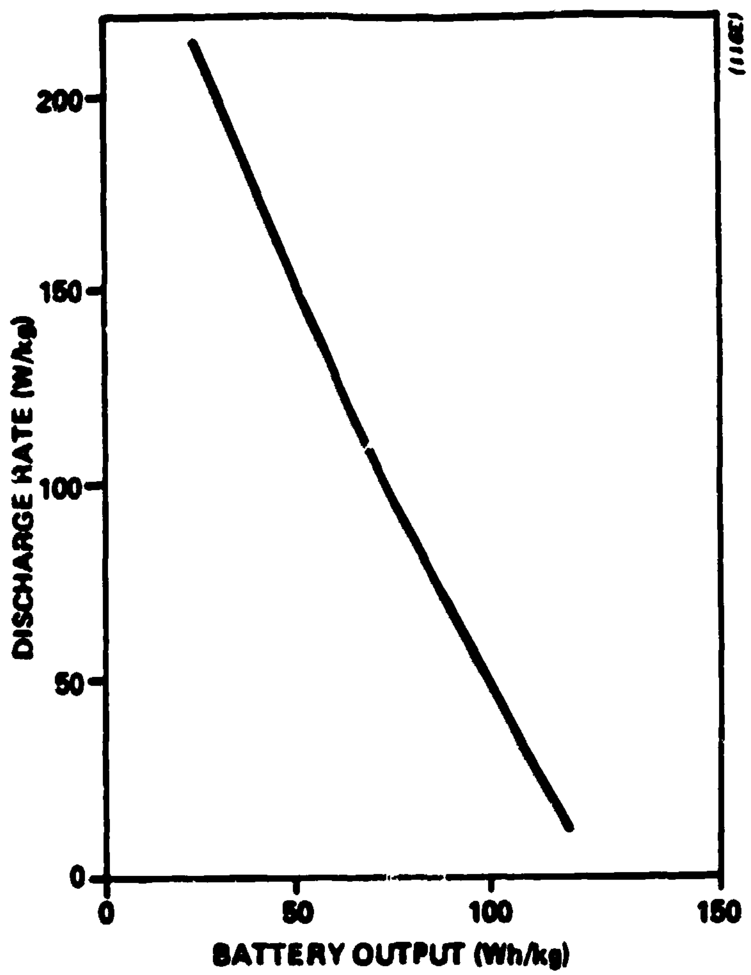


Figure B-4 Specific energy of bipolar lithium alloy-iron monosulfide battery as a function of constant power discharge rate.

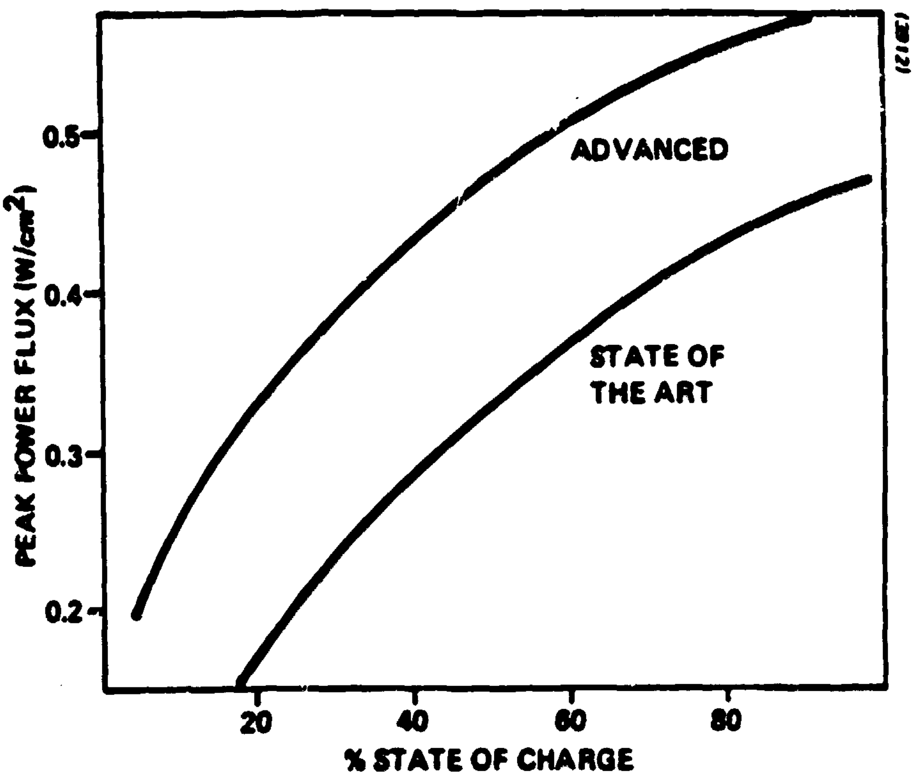


Figure B-5 The peak power flux for lithium alloy-iron monosulfide electrodes as a function of state-of-charge.

Table B-2

Peak Power of Bipolar Battery at Various States-of-Charge

	Specific Peak Power (W/kg) at State of Charge (%)			
	80	50	30	10
Advanced	272	233	188	129
State-of-the-Art	213	163	114	49

Prepared for Jet Propulsion Laboratories
Pasadena, CA 91109
Contract No. 956761

Gould Research Center
Materials & Devices Laboratory
March 12, 1984

Appendix C

BATTERY MANUFACTURING COST PROJECTIONS

I. Introduction

The cost projections are based on existing technology at Gould for the monopolar-prismatic battery and have assumed some modest improvements in this technology for estimating the cost of the bipolar battery.

The present technology at Gould utilizes a lithium-aluminum-silicon negative electrode and an iron monosulfide positive electrode. The separator is magnesium oxide powder and the electrolyte is a ternary lithium halide salt of 22 w/o LiCl-68 w/o LiBr-10 w/o LiF. The current collection system is fabricated from Nickel 200 in order to provide good electrical conductivity. All other hardware is made from Grade 304 stainless steel.

The plant for manufacturing these batteries at the rate of 100,000 units/year is assumed to be highly automated and hence manual labor is minimal. All the processing steps involved in manufacturing Li-MS batteries are typical of present-day battery and powder metallurgy establishments. The only special feature of a Li-MS battery plant would be that a number of the processing steps have to be performed in a dry-room atmosphere since the negative active material and electrolyte are highly moisture sensitive. It has been assumed that most of the cell hardware components will be bought-in items since they can be readily made by conventional metal stamping and forming operations. Many of the cell components are already made this way even for our present needs.

II. Cost Analysis

The following cost analysis has been performed as per the ADL guidelines* except where indicated in the following and noted in the tables of this appendix.

The main assumptions in the ADL costing methodology and deviations proposed are:

i) Overhead Rates

The labor overhead rate is 150% of the direct labor and the materials overhead is 10% of the materials cost. It should be noted that in the Consiglio/Symons costing, (see Table C-2) they applied a 280% labor overhead rate. In their report they reference this overhead rate to Gould. However, it should be pointed out that when this rate is applied it includes equipment depreciation, rent and warranty costs. Therefore their analysis will be somewhat high since they have included these costs twice, but figured in two different ways.

ii) Direct Labor

In this analysis we have chosen to figure the direct labor as 9% of the materials cost, instead of at a fixed hourly rate.

iii) Equipment and Depreciation

The capital equipment costs have been figured on the basis of $20/kWh for the theoretical capacity within the battery. The capital equipment has been amortized linearly over a ten-year period, hence a 10% depreciation factor is used in the calculation.

---

*EPRI Report No. 787-1 November 1976.

iv) Rent

This has been figured at $6/ft^2 for the conceptualized plant.

v) Working Capital Requirements

The working capital requirements are assumed to be equal to 30% of the value of annual production based on the factory cost.

vi) After-Tax Return on Investment and Taxes

Each of these two items are assumed to be equal to 15% of the total investment on an annual basis. The total investment is the sum of the equipment cost plus the working capital.

The basic raw material prices used in the calculations are listed in Table C-1 and a summary of the costs leading to the estimates for the OEM selling price for both monopolar prismatic and bipolar batteries are given in Table C-2. For comparison, the costing performed by Consiglio and Symons is listed also in Table C-2. However, it should be noted that their costs are based on an annual production rate of 20,000 batteries whereas the Gould estimates are for a rate of 100,000 units per year.

Table C-1 Market Price of Materials* 1984

Material	Market Price $/kg
Lithium Metal	47.74
Lithium Bromide	14.32
Lithium Chloride	6.60
Lithium Fluoride	10.38
Aluminum	2.38
Silicon	1.45
Iron Sulfide	0.90
Magnesium Oxide	1.76
Potassium Chloride	0.12
Nickel	14.48
Stainless Steel	3.01
Iron Powder	0.62
Low Carbon Steel	0.73

*Chemical Marketing Reporter February 84
American Metal Market March 84

Table C-2. OEM Selling Price for Lithium-Metal Sulfide Batteries (Battery Size - 25 kWh delivered at C/3 rate)

Cost Item	1984 Dollars/Battery			Remarks on Gould Costing
	Consiglio/Symons 20,000 Batts/yr	Gould 100,000 Batts/yr		
	Monopolar	Prismatic	Bipolar	
Materials				
Lithium Bearing Compounds	1552	1405	1265	
Other Materials	690	600	300	
Insulating Enclosure	650	290	290	$10 per kWh
	2892	2295	1855	
Material Overhead	289	229	186	10% of Material Cost
	3181	2524	2041	
Direct Labor				
Cell	241	207	167	9% of Material Cost
Cell/Battery	60	52	42	25% of Cell Labor
	301	259	209	
Direct Labor Overhead	843	389	314	150% Direct Labor
	1144	648	523	
Equipment Depreciation	100	58	56	
Rent	63	48	42	
Factory Cost	4488	3278	2662	
Capital Investment				
Working Capital	1346	983	799	30% of Factory Cost
Equipment	1000	580	560	$20 per kWh
Total Investment	2346	1563	1359	
ROI + Taxes	704	469	408	30% of Total Investment
Warranty	100	100	100	
OEM Selling Price	5292 ($212/kWh)	3847 ($154/kWh)	3170 ($127/kWh)	

III. Summary Remarks

It can be seen from Table C-2 that the cost per kWh for lithium alloy-metal sulfide batteries employing existing technology are substantially more expensive than the desired $100/kWh target for the advanced battery systems in electric vehicle applications. However, a major portion of the cost is attributed to the lithium bearing compounds (i.e. ~40%). Therefore, if the cost goal is to be attained, this area should receive greatest attention. In the report[1] submitted by ANL under this contract, Chilenskas and Shimotake have proposed a number of feasible ideas which can be shown to significantly reduce the price of lithium-metal sulfide batteries. In particular they have suggested using lithium carbonate as an inexpensive feed stock for manufacturing all the required lithium bearing compounds necessary for the battery. It may be possible also to use a LiCl-KCl electrolyte in place of the all-lithium-halide electrolyte in the less demanding vehicle applications.

The OEM selling price from this and the ANL report is projected to be in the range of $154-99 per kWh. The upper end of the range relates to existing technology whereas the lower end can probably be realized in a second generation plant.

Appendix D

LIFE CONSIDERATIONS

I. Cells

A summary of the cycle-life tests performed on Gould immobilized-electrolyte-powder separator type cells (see Figure 2) at both ANL and Gould is presented in Table D-1. The tests performed at ANL were on cells specifically designed for the EV application. These cells were cycled on a 12 hour regime (i.e. 8h charge/4h discharge) to 100% DOD or 1.0 V lower cut-off voltage. The end of life was defined as either a 20% loss in the initial capacity or a decline in the coulombic efficiency below 95%. The highest mean-time-to-failure for these cells was 330 cycles; with a Weibull Slope, which defines the distribution of failures of 2.9. The average capacity loss was 0.06% per cycle.

The tests performed at Gould were on cells designed for a high rate application and consequently the specific energy is substantially reduced due to the heavier current collection system. The electroactive materials, electrolyte and separator, however, were essentially the same as those in the Group II EV cells. Two different test regimes were examined, one was a 6h regime (5.25h charge, 0.75h discharge) the other a 24h regime (22.8h charge, 1.2h discharge). The cells were discharged also to different depths-of-discharge between 40% and 80%. The end of life for these cells was when the leakage current exceeded 1000 mA.

It was concluded from the Gould tests that the cell life is somewhat dependent upon depth of discharge (i.e. longer life for lower depths of discharge) but this is a second order effect and the primary factor limiting the life of the Gould cells is the time at operating temperature. This time is in the region of 150 days and is arrived at by dividing the number of cycles by the cycles per day of the test regime.

Table D-1. Summary of Gould Li Alloy-FeS Cell Performance in Tests at ANL and Gould

	Status Cells Tests (ANL) I	II		Gould Tests A	B	C	D	E
No. of Cells in Group	12	12		5	9	5	5	5
Theo. Capacity Ah	194	194		119	119	119	119	119
Av. Operating Temp., °C	465	a		465	465	465	465	465
Av. Peak Capacity, Ah	158	157		101.3	101.0	101.3	100.8	100.0
Std. Dev. in Peak Capacity, ±%	4.5	3.2		2.1	3.6	1.8	3.2	4.3
Av. Specific Energy, Wh/kg	74	80		69.7	69.3	69.1	68.5	68.4
Peak Specific Power, W/kg at 50% DOD	70	70		100±10	100±10	100±10	100±10	100±10
Cycle Life[b] to % DOD	100	100		40	60	80	60	80
High/Low, Cycles	307/14	467/121	542/158[e]	1260[+]/364	865/355	828/261	315/90	338/85
Mean Time to Failure Cycles	218/26[c]	268	330	832	634	570	164	177
Weibull Slope	2.0/3.4	3.1	2.9	--	--	--	--	--
Av. Capacity Loss Rate, % per Cycle		0.08	0.06	--	0.015	--	--	--
Charge/discharge cycle, h	8/4	8/4		5.25/0.75	5.25/0.75	5.25/0.75	22.8/1.2	22.8/1.2

[a] Temperature was 455°C until 20% capacity loss, then raised in 5° increments to 455-475°C.
[b] End of life defined as 20% capacity loss or coulombic efficiency decrease to <95%.
[c] Correlated as five- and seven-cell groups. Single group correlation not possible.
[e] Gould Status Cells, Group II, showing the improved performance obtained by raising the temperature to 475°C.
[+] Cells still cycling.

The failure mechanism which is limiting the life of these most recent cells has not yet been investigated. Post-test examination of earlier cells, however, has shown the failure to be due to shorts which develop as the positive active material is exuded through the particle retainer basket into the separator and eventually this material comes into contact with the negative electrode, or other conductive material that with time becomes deposited in the separator layer (i.e. iron particles).

Recent Eagle-Picher cell tests, performed under a program for the U.S. Army, have demonstrated a life in excess of 1000 cycles and 500 days of operation to 80% DOD. Therefore, there is no reason to believe that with modification the Gould immobilized electrolyte-powder separator cells cannot achieve a similar lifetime at temperature.

II. Battery Modules

Within Gould minimal lifetime information has been generated on Li alloy-MS battery modules since only three have been assembled and tested. One of these was a three cell module and the other two were ten-cell 2.5 kWh modules. However, a reasonable amount of operational experience and information was gathered during the testing of these latter two modules. The early performance of the modules were as expected with the battery capacity declining steadily with cycling as the cell imbalance increased due to minor differences in the coulombic efficiency of the cells. The full battery capacity, however, could be restored by performing an equalization after ~14 cycles. It was possible to repeat this cycling-equalization routine at least 5 times before problems arose with the batteries. These problems were partially attributable to electrolyte leakage from the positive feedthrough seals and the subsequent "wicking-action" along the insulation on the intercell connectors. In general the life of the two battery modules was in line with the cycle life of the individual cells from which they were constructed. The thermal management systems used in these battery modules were capable of maintaining the cells within their operating temperature range during both charge and discharge and it was concluded that a minimal cooling system will be required.

As part of the current EPRI program, Gould is to build 9-cell battery modules that are to be tested at ANL in a high-efficiency thermal insulated housing fitted with an integrated thermal management system. This system will provide both heating and cooling during operation of the battery.

APPENDIX H

BATTERY DESIGN ANALYSIS

BATTERY DESIGN ANALYSIS

FEBRUARY 1984

Prepared for

Jet Propulsion Laboratory
California Institute of Technology

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BATTERY DESIGN ANALYSIS

Final Report
February 1984

Contract No. 956727
Jet Propulsion Laboratory
California Institute of Technology

Submitted by _______________ Date 3/1/84
R.W. Minck
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Approved _______________ Date 3/1/84
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Advanced Battery Engineering

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SUMMARY

A brief design analysis was performed which confirms that sodium-sulfur (Na/S) batteries can be designed to match a wide range of mobile application requirements. These missions range from low-power commuter EVs to full performance EVs to very high power hybrid vehicles. In spite of the need for high temperature operation, the projected specific energy, power density and energy efficiency of the complete Na/S battery system are excellent, enabling all the missions to be considered technically viable. Economic estimates are less certain, but indicate that battery initial cost is likely to be relatively high. Economic viability would depend on alternate fuel costs as well as on attaining the projected cycle life and high-rate production.

It would appear that the appropriate next step should include demonstration of hardware and validation of projections for both performance and cost.

INTRODUCTION

The applicability of sodium-sulfur batteries to a wide range of mobile missions was addressed in this brief analysis. The influence of battery size and power-to-energy ratio was determined at a system level through a series of four point designs, each targeted at a representative application. These include three EV vehicles and a battery hybrid vehicle. In all cases, the exceptional efficiency and high specific energy of individual cells lead to practical performance projections for the complete battery systems. Obviously, larger batteries are favored as a consequence of the weight and volume requirements for thermal control, but even the small commuter battery has a specific energy of about 90 Wh/kg.

These analyses addressed issues of thermal and charge control, packaging, overall energy balance, aging, maintenance and cost estimates. For this study, the design guidelines supplied by JPL were followed with few exceptions in order to facilitate battery comparisons. As a result, some performance paramaters are lower than could otherwise be claimed with a more detailed design. In areas of battery reliability, maintenance and cost, the state of Na-S technology development does not support firm projections.

1.0 PERFORMANCE MODELLING

Four candidate missions were specified along with their energy and power requirements. These are listed in Table 1.1. Using assumptions specified in the guidelines and augmented by the others discussed with the JPL Program Manager, sodium-sulfur batteries were designed for each of the four missions. The principal assumptions are listed in Table 1.2.

The sizing (initial rating) of each battery is increased by 10% in both energy and power to approximately offset deterioration during life. The balance between credits for providing excess capability in early life and penalties for having inadequate performance in later life is poorly quantified. The issue is clouded by the probable spread in customer tolerance to performance shortfall and willingness to follow recommended maintenance schedules. The fixed 10% factor for all missions is considered more appropriate than trying to estimate separate life-cycle averages for each mission. Small additional adjustments are made to the power and energy goals of each mission to compensate for controller limitations. The performance ratings of the batteries are estimated in accordance with the guidelines (i.e., 1-year battery), and battery outputs over life are projected Section 5.

1.1 BATTERY DESIGN

In this study, it is assumed that cells are connected in long series strings to provide either full- or half-battery voltage. Full battery capacity is obtained by parallelling the appropriate number of strings. The response of long strings is to average (sum) the individual cell resistances, thus reducing the effect of cell variability. However, the effective string capacity is determined by that of the weakest cell since it blocks further current. Based on present modelling studies, this long string interconnection topology appears to provide best battery reliability.

Table 1.1. Candidate Missions

	APPLICATIONS	RANGE	ENERGY CONSUMED	MAXIMUM PULSE POWER DEMAND
I.	Commuter EV	128 km	12 kWh	25 kW
II.	Hybrid Vehicle	80 km	15 kWh	50 kW
III.	General Purpose EV/Van	160 km	25 kWh	60 kW
IV.	Full Performance EV	400 km	50 kWh	50 kW

Table 1.2. Assumptions for Performance Modelling

1. Controller Voltage Range Fixed Over Life
   - o Nominal 240 V battery (except 120 V for commuter)
   - o Allowable range: OCV↔0.54 OCV
   - o No provision for regeneration voltage
   - o Controller limits removed for charge
2. Mission Requirements Considered "Mid-Life"
   - o 110% used to size "new" battery
   - o 1-year old battery used to project performance
   - o 1-year old battery used for "energy balance"
3. Battery Aging Model (circa 1990)
   - o dN/N = -0.0C[illegible] per freeze-thaw cycles (N = number of good cells)
   - o dN/N: Weibull statistics (α = 1500 cycles, β = 3.0)
   - o dR/R = $+(1.0\pm0.5)\ 10^{-4}$ per electrical cycle (R = resistance)
   - o dC/C = $-(1.0\pm0.5)\ 10^{-4}$ per electrical cycle (C = capacity)
   - o Failed cells have 1 mΩ resistance
4. Balance of System Components
   - o Structural support weight proportional to cell weight.
   - o Thermal enclosure size & losses scale as $(\text{volume})^{2/3}$
   - o Thermal control proportional to square of sustained power.

For Na/S cells, the principal design factors are the capacity (both theoretical and rated) and internal resistance (both pulsed and steady). The resistance values are nearly constant throughout a cycle except at the extreme ends of the charge or discharge. The common convention in Na/S technology is to define theoretical capacity between "sulfur" as charged and "Na_2S_3" as discharged. At Ford Aerospace, a linear chemical state-of-charge scale is used which conveniently represents the relative Ah content for a sulfur-limited design. Using the F-scale (corresponding to composition $Na_{2F}S_3$), the theoretical capacity ranges from sulfur (F=0) to Na_2S_3 (F=1). A value F_1 represents the end of charge defined by the dynamics of the recharge processes which are affected principally by the charge rate, voltage limit and temperature. Similarly, F_2 represents the dynamic end of discharge. The utilization (U) of the sulfur electrode is F_2-F_1 and thus depends on operating conditions.

It may be desirable for other system considerations to limit the range of cathode operation and define "design" or "rated" values for F_{1R}, F_{2R} and U_R. In this present study, the design F_{2R} is chosen between 0.6 and 0.8 for reasons related to improving the constancy of pulse power, for reduction of entropic heating, and in order to retain more voltage swing at the end of discharge (EOD) to offset additional battery deterioration thereby extending the interval before maintenance. The 100% state-of-charge (SOC) condition corresponds to the design point F_{1R}, and the 0% SOC corresponds to F_{2R}. With this convention, the battery can operate beyond the 0% - 100% range in SOC. The relationships of these notations to cell voltage are depicted in Figure 1.1.

In other EV analyses, it was often desirable to provide some "limp-home" range at less than specified power. To do this with Na/S technology,

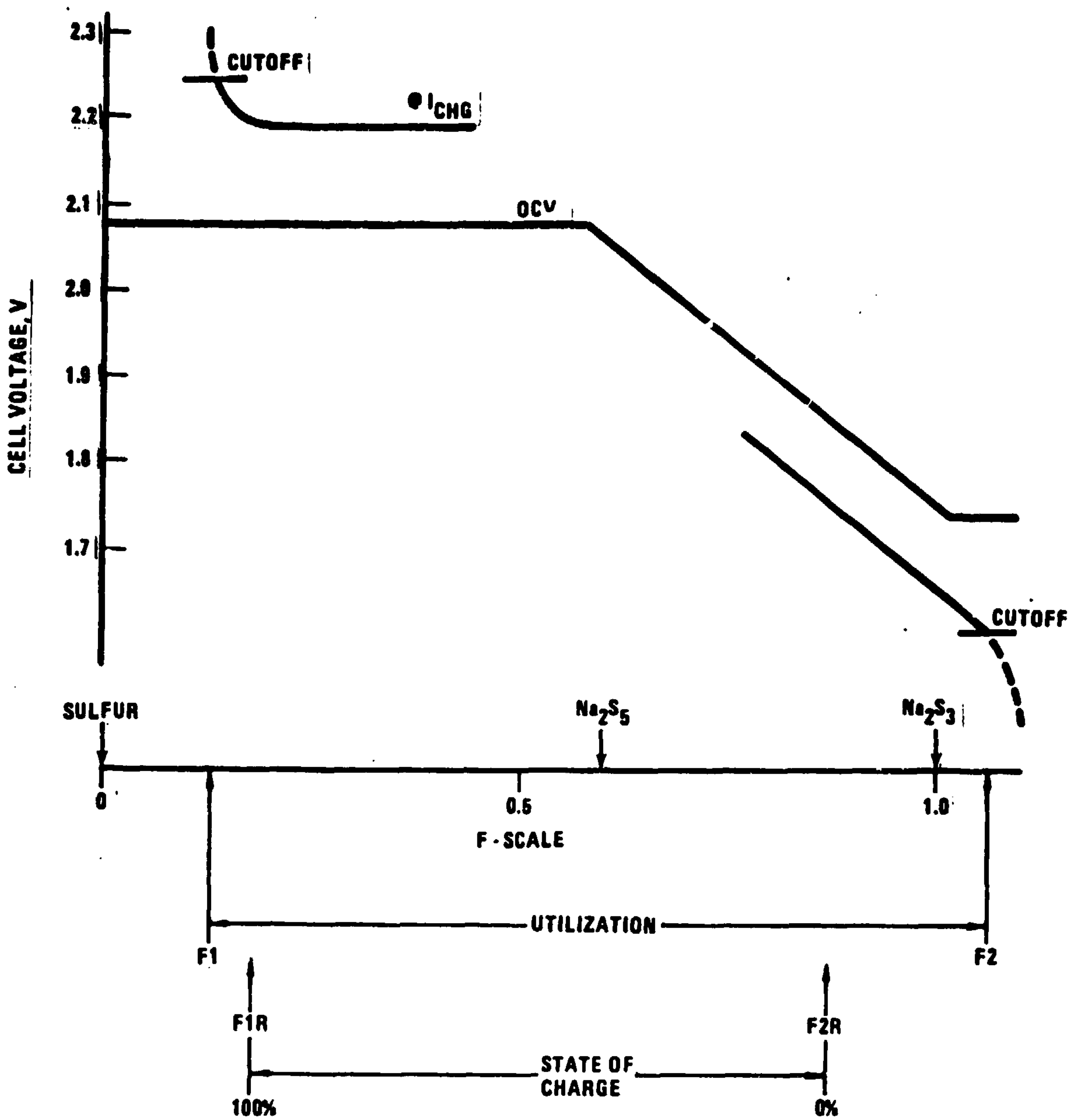

Figure 1.1. Relationship of State of Charge and F Values.

the battery is designed to meet or exceed specified power out to its rated discharge condition, $F2_R$, until it reaches its defined end-of-life. By increasing the cells' sodium content slightly, additional range capability at lower power is provided at very low incremental weight and volume. Furthermore, with its higher performance early in life, the battery can deliver the specified power throughout the additonal range as well. However, in keeping with this study's guidelines, no "limp-home" provision is included.

1.1.1 INITIAL SIZING

Throughout most of its discharge cycle, the Na/S cell is well represented as a fixed linear resistor in series with a voltage source which varies slightly with SOC, as shown in Figure 1.1. Because part of the voltage loss results from concentration polarization which is nearly linear with current, the effective resistance for pulse operation is somewhat lower than for steady operation (e.g., $R_p/R_s \sim 0.8$ to 0.95). This is beneficial in meeting the peak power specifications.

With the simple linear electrical circuit, the relationships between energy, power, efficiency, voltage, current, capacity and time are straightforward. The voltage range set by the motor/controller interacts with the battery characteristics to limit the deliverable energy and power. In this study, the voltage ratio $K_1 = V_{min}/V_{max} = 0.54$ was selected to correspond to the hardware under development at JPL and the DOE-Ford ETX program. These controllers operate between 265 V and 143 V. By removing provisions for regeneration in a new battery, the battery OCV is taken as large as possible: thus $K_2 = \text{OCV (@ SOC = 100\%)}/V_{max} = 1.0$. For convenience, several other ratios were defined. The cell's OCV varies with SOC as shown in Figure 1.1, with $K_3 = \text{OCV (@ SOC = 0\%)/OCV (@ SOC = 100\%)}$ varying from 0.85 to unity as a

function of the selected F_2 value for the cathode. The delivered energy is related to the average cell voltage, hence to the average OCV. The ratio, $K_4 = \overline{OCV}/OCV$ (@ SOC = 100%), is very nearly unity. Although the sulfur electrode response to pulse loads differs appreciably from its steady operation, the ratio of cell resistances, $K_5 = R_p/R_s$, varies with design and is seldom less than 0.8.

Using these normalizing factors, the response of a new battery can be approximated as follows:

$$E_{DEL} = (\overline{OCV} = I_D R_S) \cdot C$$

$$= V_{max} \cdot K_2 \cdot K_4 \cdot C \cdot \overline{\eta}_D \quad (1)$$

$$P_{AVG} = E_{DEL}/T_D \quad (2)$$

$$PP_{DEL}(SOC = 0) = I_P V_{MIN}$$

$$= V_{MAX}^2 (K_2 \cdot K_3 - K_1) K_1/R_P \quad (3)$$

$$PP_{BAT}(SOC = 0) = V_{MAX}^2 (K_2 \cdot K_3)^2/4 R_P \quad (4)$$

where $\overline{\eta}_D = 1 - (I_D R_S/\overline{OCV})$ is average discharge efficiency;

V_{MAX} and V_{MIN} are controller voltage limits;

R_P, R_S, and C are pulse and steady resistance, and capacity of the b

T_D, and I_D are effective time and average current during motoring

and $K_1 \ldots K_5$ are ratios defined in text.

The initial capacity of the battery must be oversized by a factor $(1/\overline{\eta}_D)$ to account for voltage losses. The peak battery power at SOC = 0 must exceed the vehicle demand by a factor $K_2^2 K_3^2/4K_1(K_2K_3-K_1)$ to offset the controllers' voltage range limitation. The resulting beginning-of-life goals

for the four missions are adjusted by the appropriate factors and are summarized in Table 1.3. A representative cell design for each mission is then generated. Salient features of each cell are listed in Table 1.4, along with the resulting initial battery characteristics.

1.1.2 ONE YEAR OLD BATTERY

The effect of cell deterioration and cell (electrolyte) failures on the response of the Na/S battery is strongly influenced by cell interconnection topology. Present analyses indicate a preference for several long "strings" of cells, parallelled at the battery terminals. Under these assumptions, the battery characteristics decay gracefully.

Three modes of cell deterioration are assumed: electrolyte fracture, resistance rise, and capacity decline. Present experience indicates that some failures occur with the freeze-thaw phase change, and other electrolyte failures follow a Weibull statistic. The effect of cell loss is to reduce the OCV by an amount proportional to the fraction of failed cells in the battery. (Unsymmetrically distributed failures cause temporary unbalance in string currents, but these generally average out when the cell OCV begins to fall near the end of discharge.) The effect of 1-year service ($<10{,}000$ miles/year or ~ 250 partial cycles) is modelled as an equivalent number of full cycles which provides the same range.

Cell performance deteriorates continuously with service with resistance and capacity worsening at an average fraction rate of 1×10^{-4} per cycle. The present average rate and width of distribution of decay rates are projected to improve by 1990 technology (Table 1.2).

Table 1.3. Initial Sizing Goals for Batteries

		I Commuter	II Hybrid	III EV/VAN	IV Full Perf.
Range	(km)	128	80	160	400
Discharge Time	(h)	2.0	1.25	3.0	5.0
Charge Time	(h)	8.	8.	8.	12.
Average Power	(kW)	6.0	12.0	8.33	10.0
Sustained Power*	(kW)	12.5	25.	25.	25.
Nominal Volts	(V)	120	240	240	240
Energy	(kWh)	13.2	16.5	27.5	55.0
Peak Power**	(kW)	27.9	55.4	67.1	56.8

* for 20 minutes
**at SOC = 0%

Table 1.4. Initial Characteristics - Cells and Batteries

CELLS		I Commuter	II Hybrid	III EV/VAN	IV Full Perf.
OD	(cm)	3.02	2.74	3.18	3.78
Length	(cm)	31.9	29.6	35.4	35.1
Weight	(g)	473	380	582	755
Volume	(cm^3)	229	175	280	394
Capacity	(Ah)	37.8	23.7	38.4	77.8
Energy	(Wh)	73.6	46.2	76.7	153
PP*	(W)	155	154	186	158
Dis. Eff.	(-)	0.943	0.938	0.968	0.957
Pulse Resistance*	(mΩ)	6.36	6.91	5.30	5.73
SE	(Wh/kg)	156	121	132	202
ED	(Wh/l)	322	264	274	387
SPP*	(W/kg)	328	405	320	209
PPD*	(W/l)	678	880	664	400

BATTERIES					
No. of Cells	(-)	180	360	360	360
OCV (SOC = 100%)	(V)	124	249	249	249
Capacity	(Ah)	113	71	115	233
Resistance - steady	(mΩ)	137	296	224	247
- pulse	(mΩ)	127	276	212	229
Energy	(kWh)	13.3	16.6	27.7	54.9
PP*	(kW)	27.9	55.4	67.0	56.8

* At SOC = 0%

The effect of resistance rise is determined principally by the average rise rate since long series strings average the distribution. However, capacity decline rate is established by that of the worst cell in the string. Thus a $(\overline{X} - 3\sigma)$ value is appropriate for the worst cell in a 360-cell battery. Extreme capacity loss (e.g., >20%) would be prevented (eliminated) by a maintenance operation which shorts out the cell.

The projected deterioration factors for a 1 year old "1990" battery are listed in Table 1.5, along with resulting battery characteristics for the four missions.

1.1.3 STRUCTURAL AND PACKAGING

Each cell must be electrically insulated to prevent shorting to its neighbors. Sixty-cell groups are then assembled into modules and supported by an enamelled steel enclosure. Provisions for cell interconnections, bus bar connections, heaters, and thermal control are included within the module structure. The modules are enclosed within a vacuum thermal insulation enclosure. The thermal control system and battery are supported on a tray bolted onto the vehicle frame.

The weight of the module hardware is modelled as proportional to cell weight and estimated by analogy to Ford Aerospace's CARBAT-1 experience. The weight of the thermal enclosure is scaled as the 2/3 power of battery size. Weight of the thermal control system is taken proportional to the square of sustained power which reflects the heat rejection requirements.

Estimates of the packaging requirements include: 5-mm allowance between modules and around the outside of the module pack; 3-cm allowance for internal support platforms including heating/cooling ducts; a 2.5-cm thick evacuated

Table 1.5. Characteristics of 1-Year Old Battery

		I Commuter	II Hybrid	III EV/VAN	V Full Perf.
Cumulative Range	(km)	12000	16000	16000	24000
Equivalent Cycles	(-)	100	150	100	60
Deterioration Factors*(1990 Technology)					
Electrolyte Failures		0.0033	0.0040	0.0031	0.0031
Resistance Rise		1.010	1.015	1.010	1.006
Capacity Decline		0.976	0.964	0.976	0.984
Battery Characteristics					
No. of Cells	(-)	179	358	359	359
OCV (SOC=100%)	(V)	123.8	247.5	248.2	248.2
Capacity	(Ah)	110.6	68.6	112.2	229.8
Energy	(kWh)	12.86	15.90	26.88	53.91
Peak Power (SOC=0%)	(kW)	27.47	54.24	66.14	56.24
Peak Power (@ V_{min}, SOC=0%)	(kW)	26.98	53.77	65.01	54.40
Average Dis Eff.	(-)	0.942	0.937	0.968	0.957

*Multiplicative Factor

enclosure, and a 12.5-cm long bottom superinsulating end plug which provides space for the air blowers, fuses, connecting plugs, and microprocessor-based charging control. The charger is off-board and not included in this analysis.

A summary of the weights and sizes of the battery components and for the total system is given in Table 1.6.

1.1.4 BATTERY DISCHARGE CHARACTERISTICS

For each 1-year old battery, the energy delivered at various discharge rates is calculated. These calculations are based on the "steady" resistance value and average OCV and result in a Ragone curve. The discharge characteristics are summarized in Table 1.7.

The variation in deliverable peak pulse power throughout the discharge cycle is calculated by using the batteries' pulse resistance and the voltage difference between the battery OCV and controller limit, V_{MIN}, to determine maximum pulse current at the controller voltage. The results are presented in Table 1.8, and are very flat as a consequence of limiting the design depth of discharge and avoiding the normal voltage droop associated with a deeper depth of discharge.

Table 1.6. Size & Weight of Battery System

	I Commuter	II Hybrid	III EV/VAN	IV Full Perf.
60-Cell Module				
Width (cm)	14.4	13.1	15.1	17.8
Length (cm)	40.3	36.8	42.2	49.8
Height (cm)	33.9	31.6	37.4	37.1
Volume (l)	19.6	15.2	23.8	32.8
Σ Cell Wt. (kg)	28.4	22.8	34.9	45.3
Total Weight (kg)	34.6	27.8	42.6	55.3
Module Pack with Support & Thermal Manifolds				
Module Arrangement	3 x 1	3 x 2	3 x 2	3 x 2
Width (cm)	45.1	43.0	48.7	56.7
Length (cm)	42.1	75.0	86.0	101.0
Height (cm)	36.9	34.6	40.4	40.1
Volume (l)	70.1	111.5	169.1	228.8
Manifold & Support Tray (kg)	5	7	10	13
Weight of Modules (kg)	103.9	116.9	255.6	331.6
Total Weight (kg)	109	174	266	345
Thermal Enclosure				
Outer Dimensions (cm)	50.2	48.0	53.8	61.6
Length (cm)	47.2	80.1	91.1	106.1
Height (cm)	52.1	49.8	55.6	55.3
Volume (l)	124	192	272	362
Weight (kg)	21	28	35	42
Blowers & Ducts (kg)	5.0	10	10	10
Misc. Weight (kg)	10	15	15	15
Total Battery Weight (kg)	145	227	326	412
Total Battery Volume (l)	124	192	272	362

Table 1.7. Discharge Characteristics after 1-Year Service

Sp. Energy (Wh/kg) vs. Discharge Rate

Battery Design	Specific Power (W/kg) 20	40	60	80	100	150	200
Present	85.8	80.2	73.5*	-	-	-	-
Commuter	91.5	88.8	86.0	82.9	79.5	68.8*	-
Hybrid	73.1	71.3	69.4	67.4	65.2	59.0*	49.9*
EV/VAN	83.4	81.2	78.8	76.3	73.5*	65.3*	-
Full Performance	131.9	126.7	121.0	114.6*	107.1*	-	-

*May require increased heat exchange for prolonged operation.

Table 1.8. Specific Pulsed Power After 1-Year Service
Limited by Controller Voltage

Battery Design	Sp. Pulsed Power (W/kg) vs State of Charge SOC = 80%	50%	30%	10%	0%
Present	122	122	105	87	79
Commuter	211	209	207	198	186
Hybrid	247	244	242	241	237
EV/VAN	227	224	222	212	199
Full Performance	167	165	162	143	132

2.0 COST PROJECTIONS

Funding did not permit a detailed cost analysis to be performed for this study. Estimates of OEM cost were derived by extrapolation and revision of prior (1980) costing studies that had been performed as part of Department of Energy Contract No. DE-AM04-79CH10012.

A number of modifications were incorporated into the 1980 study to generate the present estimates. These include:

a) Allowance for balance of system costs ranging from $600 to $1000

b) Use of recommended scaling factors for high production rates: vis. materials $\sim$(Production Rate)$^{0.9}$, labor $\sim$(PR)$^{0.6}$, and capital equipment $\sim$(PR)$^{0.6}$

c) The electrolyte assembly was costed at \$0.015/cm^2 of electrolyte surface (at 10^7/year) on the basis of purchase from a supplier, rather than internal manufacture.

d) Capitalization only for cell assembly and battery fabrication

The results of these price projections are presented in Table 2.1 which gives battery selling price to vehicle OEM manufacturers for each of the four missions. In addition, the cost of incremental cell production is estimated for each cell type. No information is listed for "present design" since it is at the first engineering prototype stage.

The conductive ceramic electrolyte is the dominant cost item in the cell, accounting for $\sim$80% of its material costs. A sensitivity analysis to the cost of electrolyte was made. For a 10% increase in electrolyte cost, the incremental cell price increased by 6% and battery price increased by 3%.

Table 2.1. Battery & Cell Price Estimates

Battery Design		Battery Selling Price	Cell Price
I.	Commuter	$2430.	$4.92
II.	Hybrid	3128.	4.13
III.	EV/Van	3802.	5.63
IV.	Full Performance	4059.	6.13

3.0 TECHNICAL SUPPORT FOR PROJECTIONS

A number of improvements are under development in the laboratories of Na/S developers, or have been identified as critical needs. R&D efforts are being initiated to establish the technical base for resolution of these present shortcomings, none of which appear to be of fundamental nature.

Improvements in cell components are expected for nearly every element in the cell, especially in regard to cost reduction and quality control. Manufacturing development will overcome many present difficulties associated with lack of reproducibility. The anticipated modifications to the battery and balance-of-system components relate to engineering refinements of the structural, thermal and charge control designs. A listing of probable changes is provided in Table 3.1.

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Table 3-1. Technical Support for Projections

	Present Status	Design Change	Performance Change	Cost Change	Comments
A. Cell					
Electrolyte	High quality Baikowski α-alumina starting powder	Low Cost Powders	0-20% resistance increase	<\$2/kg vs. \$15/kg	Battery developers are working with alumina suppliers to provide control on specific impurities in low cost powders.
	Zeta processing	Spray dried powders	Thinner, lower resistance electrolytes	Faster, automatic green forming, Eliminates calcining and bisquing steps	Permits high rate dry bag process.
	Batch sintering	Continuous sintering	More uniform product	Reduced energy consumption and higher throughput	Adaptable to single step sinter/anneal process. Single furnace supports high rate production.
	Manual inspection & QC	Automated QC	Eliminate defective parts More uniform product.	Improved yield Reduced touch labor	Improves battery reliability by providing better component uniformity.
Sodium Electrode	High purity sodium	Selective impurity control	Increased life	\$1/kg vs. \$10/kg	Combine with automated filling & sealing.
Sulfur Electrode	Rayon precursor graphite	Pitch based fibers	None	\$10/kg vs. \$250/kg	- - -
Positive Current Collector	Chromium based corrosion protection layer	Improved chromium	Increased life	None	Eliminate occasional defective coating.
		Conductive glass, oxides or other layers	Stable performance	Reduced labor & energy	Enamelling operation is in common commercial use.
	Steel substrate	Aluminum cladding	Improved electronic conductivity. Reduced wt., longer cells	Some increase	Permits larger cells. Reduces cell wt. substantially. Concerned with long-term intermetallic diffusion.
Cell Assembly	Manual	Automated	Reproducible product	Reduced labor content	Requires extensive capitalization.
Cell Characteristics	3% freeze-thaw failures.	Stress relief design	<0.3% freeze-thaw failures	Negligible	Ensures good startup and maintenance of battery.
	Fail shorted.	Modified design	No penalty	Negligible	Ensures operation of long series strings.
B. Battery & Balance of System					
String/Module	Under development	Long strings	Improved load share Reduced deterioration rate Some volume increase	Negligible increase	Designed for periodic maintenance. Battery performance not critically affected by individual cell failures.
Thermal Enclosure	Initial units	Evacuated enclosure Evacuated end plugs	150 W vs. 300 W	Linde projects <\$300 cost	EV requires evacuated insulation. Single location necessary to minimize heat loss.
Thermal Control	Radiation/indirect	Combined radiation/convection	Reduced control power Supports higher exchange rate	Minor reduction	Heat exchange sized for sustained power.
Support Structure Cells/Modules	Enamelled sheetmetal with insulated cells	Reduce amount of structure	Reduced weight	Same	Design for easy maintenance.
Battery/Vehicle	Fitted to existing vehicle	Simplified installation. Interactive vehicle/battery design	Reduced weight Avoid duplicate structures	Same	Design for easy maintenance.
Charge Control and Monitoring	Many instrumentation leads	Status calculated from string response	Improved reliability	Reduced labor	Eliminates extraneous faults.
		On-board likely	Lower efficiency, wt. penalty	T.B.D.	T.B.D.

4.0 ENERGY BALANCE

The Na/S battery is very energy efficient during use because of 100% coulombic efficiency and good voltage efficiency during both charge and discharge. Thermal losses are minimized by incorporating the advanced evacuated insulation currently under development at Linde Division, Union Carbide Corporation. In addition, the large thermal mass and wide permissible range of operating temperature permit most of the electrical losses during operation to be retained to offset thermal losses during idle. During sustained high-power operation, heat must be rejected from the battery to restrict the temperature rise. In this mode of operation, thermal efficiency is lower; however, the thermal penalty is small compared to the energy consumption at high power. Since JPL-Driving Cycle #3 does not incorporate a sustained load, it does not apply to this study.

Calculations of energy balance throughout a 24-hour period were made for the general purpose EV/Van battery with a nominal 1500-kg test weight vehicle. For these calculations, a 1-year old battery condition is assumed. The recommended cycle, JPL Profile #3, was modified in two aspects for the energy balance calculations. The extreme high-power demand, 89 W/kg, (133 kW peak) is not real. The 4-second period was extended to 8-seconds to lower its average power to 47 W/kg, equal to the subsequent demand. Secondly, all power levels were reduced by a factor 1.5 to bring the maximum power demand down to more nearly proper levels (47 kW). Even with this reduction factor, the energy consumed per mile with regeneration is 398 Wh/mile, a value that is still about 1.4 times too large based on the Ford ETX projections. The modified profile used in these calculations is given in Table 4.1.

The thermal response of the battery is summarized in Table 4.2. The final temperature during each segment is estimated. The 17°C rise during

Table 4.1. Modified JPL Profile #3

Segment		Guidelines Time	W/kg	Modified Segment		Time	W/kg	1500 kg Vehicle kW
I.	1.	0-26	12	I.	1.	0-22	8	13
		26-30	89			22-30	31	47
		30-74	33			30-74	22	32
		74-76	47			74-76	31	47
		76-171	-3			76-171	-2	-3
	2.	171-196	0		2.	171-196	0	0
		196-211	33			196-211	22	33
		211-236	7			211-236	5	7
		236-251	-10			236-251	-7	-10
	3.	Same as 2			3.	Same as 2		
	4.	Same as 2 plus idle			4.	Same as 2 plus idle		

Table 4.2. Thermal Response

	Temperature Variation (°C)		Net Heat Generation (Wh)	
	W/Regen	W/O Regen	W/Regen	W/O Regen
Start of Drive	To	To	-	-
End of Segment 1	To +17.39	To +17.30	1039	1034
2	To -7.43	To -7.52	-1483	-1483
3	To +9.96	To +9.77	1039	1034
4	To -4.14	To -4.33	-843	-843
5	requires supplemental heat			

Battery Heat Capacity ~59.7 Wh/°C

Battery Heat Loss Rate ~160 Watts

Required Supplemental Heat

W/Regen 1820 Wh
W/O Regen 1870 Wh

the morning use is well within the acceptable operating range. No blower power is required. For this drive cycle, no heating or cooling is required during the daytime. About 2 kWh is required overnight to restore the battery temperature.

Calculations of the electrical battery parameters, with and without regeneration, are summarized in Table 4.3. The average electrical discharge efficiency is high, even with the peaked driving cycle. Because daily range is small, the Na/S battery operates on its voltage plateau at a high state of charge which also is the region of low entropy. The overall daily efficiency, including thermal makeup energy, is about 75%. These data are transcribed onto the guideline format in Table 4.4.

Table 4.3. 24-Hour Energy Balance

	Energy At Terminals (Wh)	Capacity (Ah)	Average Efficiency (%)	Heat Generation (Wh)
Segment I				
W/Regen	5774	27.32	85.1	1156
W/O Regen	6990	32.11	87.7	1151
Recharge				
W/Regen	13642	54.64	99.3	-292
W/O Regen	16050	64.22	99.3	-332

Overall Cycle

	Disch Energy (kWh)	Chg Energy (kWh)	DC-DC Efficiency (%)	Thermal Makeup (kWh)	Overall Efficiency (%)
W/Regen	11.55	13.64	84.7	1.82	74.7
W/O Regen	13.98	16.05	87.1	1.87	78.0

Table 4.4. Estimates of In-Use Energy Consumption

Parameters		Energy by Segments (kWh) 1	2	3	4	5
Startup & shutdown		0	0	0	0	0
Self Discharge		0	0	0	0	0
Shunt Current		0	0	0	0	0
Parasitics		0	0	0	0	0
Thermal Loss W Regen		0	0	0	0	1.82
W/O "		0	0	0	0	1.87
Delivered Energy	W	5.77	-	5.77	-	-
	W/O	6.99	-	6.99	-	-
Recharge Energy	W	-	-	-	-	13.64
	W/O	-	-	-	-	16.05
Charge Eff* (%)	W	-	-	-	-	.993
	W/O	-	-	-	-	.993

*Uses Standard Charger

5.0 LIFE CONSIDERATIONS

The service life of an EV battery is dominated by the failure modes and deterioration rates of individual cells. Some of these factors were discussed in Section 1.1.2. The selected cell interconnection topology, control strategy and maintenance procedure generally reduce the influence of cell degradation on battery response. However, certain cell failure modes could be enhanced by the battery configuration and lead to worsened life statistics for the battery than for the cell.

At this point in technology development, system reliability is one of the principal active areas of analysis. Response to the following topics is mostly qualitative and tentative.

5.1 PRESENT LIFE STATUS

Cell durability is affected by electrical operating conditions, mechanical abuse and design features in addition to the manufacturing variables. Although several thousands of cells have been tested, actual life data from carefully controlled tests are meager. Few modules have been evaluated, and only one full size EV battery has been fabricated for test.

5.1.1 CELL LIFE

For a population of 384 load-leveling cells operating about 5 cycles per week, the failure statistics give fair fit to a Weibull curve with $\alpha = 1400$ days ($\sim$1000 cycles), $\beta = 2.0$ [Ref. 1]. This on-going test began in January 1981 and has progressed to a condition in which about 20% of the cells have failed. A previous 20-cell test (circa 1980) of load-leveling cells gave a similar time projection with a shape factor near unity.

We have not undertaken a statistically significant test to determine life of our EV cells. Although many have been on test for considerable time, the test conditions are frequently varied to explore response to other variables.

The longest cycle life of an EV cell presently on test is 1100 cycles, 16 months.

The effect of depth of discharge on cell life appears minor, although excessive overdischarge is likely to damage the cell. The life limiting mechanisms were discussed in Section 1.1.2.

5.1.2 MODULE AND BATTERY LIFE CONSIDERATIONS

Many concept strategies for cell interconnection and battery maintenance are being analyzed. No thorough validation of models or optimization of design exists to date.

5.2 PROJECTED LIFE IMPROVEMENTS

The planned approach to attain improved cell life consists of incorporating more manufacturing QC with more extensive NDE, coupled with continued basic R&D efforts to identify causes of cell failure. Control of specific impurities and defects could extend life significantly and be cost effective.

A list of expected technical improvements within the cell was presented in Section 3. These improvements apply to cells of either high-power or high-energy designs.

5.3 PERFORMANCE DETERIORATION

The basic effects of resistance rise, capacity decline and cell failure during life were described in Section 1.1.2. Initial response is expected to show a linear decrease in all battery performance parameters with cycling. The linear resistance rise model produces a corresponding linear fall in peak power capability. The linearly modelled capacity decline produces a linear drop in energy. Since the efficiency is high under steady loads, the interaction of increased resistance with lower capacity does not cause further reduction in energy.

As the battery ages significantly, cell failures become more frequent. The accelerating rate of cell failures causes the battery voltage to drop at an increasing rate. Energy varies about linearly with voltage, although efficiency also begins to fall. Most significantly, the peak power delivered at the controller's minimum voltage drops quickly. The peak current is determined by the voltage spread between battery OCV and the controller V_{MIN}. Since V_{MIN} is greater than half of the initial voltage, the fractional loss of peak current is more than twice the fractional loss of cells.

An illustration of the decrease of battery performance over the early portion of life including the first maintenance operation is given in Table 5.1. In this example, the battery designed for the general purpose EV/Van mission is assumed, along with the assumptions listed in Table 1.2 for deterioration and failure rates of cells.

5.4 RELIABILITY

At present, the battery is imagined to consist of six 60-cell modules for purposes of packaging and support. However, it is assumed that individual cells can be replaced during a "cool-down" repair.

As seen in the previous example of battery aging, Table 5.1, the time-to-first-repair is long but the time between failures becomes much shorter as the battery ages. A crude estimate of a possible repair schedule calls for replacement of about 15 cells after 5, 6½, 7½, 8½, 9, and 9½ years. This schedule suggests replacement of $\sim$1/4 of the cells to obtain a 10-year battery.

Table 5.1. Deterioration of Battery Performance

In Service		Deterioration Factors			Battery Output	
Years	Cycles	No. of Good Cells	Resistance Factor	Capacity Factor	Peak Power @ SOC = 0%	Energy @ 8.33 kW
0	0	359	0.997	1.0	65.65	27.55
1	100	359	1.008	0.9757	65.01	26.88
2	200	358	0.992	0.9514	64.09	26.14
3	300	356	1.021	0.9272	62.94	25.30
4	400	352	1.022	0.9029	61.24	24.34
5	500	345	1.017	0.8786	58.58	23.18
	Repaired - Replaced 15 Cells					
5	500	359	1.046	0.8895	62.58	24.47
6	600	350	1.035	0.8674	61.78	23.23

6.0 OTHER OPERATIONAL CHARACTERISTICS

The sodium-sulfur battery has a number of distinctive operating characteristics. Many of these are incompletely characterized or are significantly affected by details of design. The following responses are provided based on our present preferred cell interconnection topology and state-of-art cell design.

6.1 SPECIAL CHARGE REQUIREMENTS

Special charge control requirements are discussed below.

6.1.1 OVERCHARGE OR OVERDISCHARGE EFFECTS

At the end of charge, the cell exhibits a high polarization related to loss of electrochemically active area. As the available polysulfide (Na_2S_5) decreases and is replaced by insulating sulfur, the charging current is focussed onto smaller areas of the electrolyte. Current densities can become large, and gradients of current density can become extremely high. Ultimately, cell voltage rises until limited by the power source or until the electrolyte fractures.

At rated current, the cells normally withstand $\sim$5 V repeatedly without failure. At low currents (1/10 rated), most cells withstand 10 V and frequently withstand 20 V without apparent damage. All electrolytes have been failed by 40 V.

Following electrolyte fracture, cell failure goes to completion in a benign mode as a consequence of the safety devices incorporated into the sodium reservoir. A possible exception occurs if the conditions prior to failure have caused excessive cell heating, and fracture occurs when the cell is already above about 450°C. Cell rupture then becomes possible.

Overdischarge of a cell with excess sodium causes the polysulfide to solidify (Na_2S_2) and either rupture the casing due to expansion, or develop high internal resistance with accompanying voltage reversal and copious heat

generation. Overdischarge of a cell with limited sodium leads to a loss of active anode area, high current densities and extreme gradients of current density.

These characteristics are not well quantified. Most cells withstand overdischarge to below 1 V. Not many cells survive voltage reversal at rated current. Following voltage reversal failure, completion of cell failure is generally benign.

6.1.2 CELL BALANCING REQUIREMENTS

With long series string connections, it is not necessary to adjust the individual cells' SOC since each functional cell is 0.99999 faradaic. Should a cell become nonfaradaic due to electrolyte deterioration, that cell is expected to be driven to failure by becoming out of balance, hence overdischarged.

6.1.3 PERIODIC DISCHARGE REQUIREMENTS

Sodium-sulfur cells do not require complete discharge cycles.

6.1.4 EQUALIZING REQUIREMENTS

As discussed above in Section 6.1.2, each string does not require internal equalization. As cell failures occur and strings become unbalanced, the ability to recharge each string to equal SOCs depends on the charging algorithm. A moderate duration of taper charge could be required each cycle to restore full capacity. This taper period is easily contained within the 8-h recharge time allotment.

6.2 MAINTENANCE REQUIREMENTS

Some maintenance options are discussed below.

6.2.1 REGULAR MAINTENANCE

Ford Aerospace has limited experience in operation of full-scale batteries. Conceptual maintenance strategies have been generated but not validated.

A plausible strategy is described below. With a 10% initial margin in battery performance, a significant number of cell failures can occur before performance falls below specifications. Deterioration is graceful. Maintenance can be scheduled at operator's convenience. During a 1-day repair, the battery would be cooled, and most defective cells replaced (perhaps cell packs or modules would be substituted and then restored ex situ). The interval between such required maintenance operations would be large at first and then shorten near end-of-life. Maintenance should not be more frequent than 6 months.

Between scheduled repairs, occasional brief maintenance could become necessary if a cell fails "open" and blocks its string current. This repair, at temperature, involves shorting out the defective cell and could be accomplished quickly if access into the thermal enclosure is provided.

6.2.2 REFURBISHMENT OPTIONS

A number of options for refurbishment have been proposed. The practicality of any of these will likely be determined by the state of health of the remaining "good" cells, and the characteristics of the cells after the refurbishment function. Some preliminary experience at Ford Aerospace is encouraging. The cost benefits of such refurbishment cannot be estimated at this time.

7.0 PACKAGING FLEXIBILITY

The sodium-sulfur battery offers good energy density provided that the system can be packaged into a single volume with reasonable aspect ratios.

7.1 VOLUME REQUIREMENTS

For the design developed for each mission in Section 1, the resulting battery volumes are listed in Table 7.1.

Table 7.1. Volume Requirements

	Mission	Volume	ED*	PD*
1.	Present	285 (1)	-	-
2.	Commuter	124 (1)	103	216
3.	Hybrid	192 (1)	82	279
4.	EV or Van	272 (1)	98	239
5.	Full Performance	362 (1)	148	150

*After 1 year service

7.2 SIZE LIMITATIONS

There is no absolute limit to cell dimensions. Present technology is based on "single-electrolyte tube" cells. To maximize active area (power) per unit seal perimeter, cell length is usually extended toward maximum manufacturability limits. At short lengths, SE, ED, and cost per unit performance are degraded because of the relatively large weight of the seals and ends and reduced energy per cell. At present, a "soft" limit of about 20 cm length applies to EV applications. Advanced cell concepts (e.g., multitube) would permit shorter cells to be developed which retain good performance characteristics.

7.3 PLACEMENT OF AUXILIARIES

Sodium-sulfur cells are self-contained and do not require external storage, pumps or crystalizers. All components are enclosed within a single thermal enclosure, except for the thermal control system and battery disconnects.

The air blower and ducting must be located near the battery and have access to the outside (preferably underneath) of the vehicle to exhaust the high-temperature air when cooling is required. The battery disconnect devices are to be mounted near the enclosure to minimize copper losses.

7.4 SCALE EFFECTS

A major feature of Na/S cells is that power and energy are separately adjustable by design of the cathode and electrolyte. The resulting scale effects for a battery are determined by both the power and energy levels.

7.4.1 SCALING FACTORS FOR FIXED P/E RATIO

When the specified power-to-energy ratio remains fixed while the size of the battery is varied, the individual cell design remains fixed. The number of cells would be varied to meet the battery output. With a smaller battery-core, the thermal enclosure and auxiliaries are reduced, but their weights and volumes do not decrease in proportion to the energy or power. Hence the resultant specific energy and energy density are degraded as size is reduced.

An example of the scaling factor effects was generated by using the commuter mission battery as base design and comparing it to 2X and 4X designs. The results are indicated in Table 7.2.

Table 7.2. Scale Factors at Constant P/E

	25 kW/12 kWh	50 kW/24 kWh	100 kW/48 kWh
SE (Wh/kg)	88.2	91.4	99.9
ED (Wh/l)	103	110	116
T_D (h)	2	2	2

7.4.1 SCALING FACTORS AT FIXED POWER

When power is fixed, the area of electrolyte is about constant. Additional energy is incorporated into the cell by increasing the reactant volumes and weights. To utilize the additional energy at fixed power, discharge time must be increased accordingly.

An example of the scaling factors applicable to this case was generated by taking the EV/Van battery design as base, and comparing to half-energy and double-energy batteries at fixed power. The resultant effects on SE and ED are indicated in Table 7.3.

Table 7.3. Scale Factors at Constant Power

		60 kW/12.5 kWh	60 kW/25 kWh	60 kW/50 kWh
SE	(Wh/kg)	55.5	82.7	116.0
ED	(Wh/l)	65.1	99.0	137.3
T_D	(h)	1.5	3.0	6.0

References

1. A.B. Gates, "Status of the Ford Aerospace Sodium-Sulfur Battery Program," Paper No. 839277, Eighteenth Intersociety Energy Conversion Engineering Conference, Orlando, Florida, August 21-26, 1983.

APPENDIX I

CONTRACTOR RESPONSE: ALUMINUM-AIR BATTERY and ALUMINUM-AIR POWER CELL RESEARCH AND DEVELOPMENT PROGRESS REPORT

CONTRACTOR RESPONSE: ALUMINUM-AIR BATTERY

by
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March 24, 1984

In the first part of this response, answers are given to the questionnaire issued by JPL in January 1984. In the second part, comments are made on the report, "Advanced Vehicle Subsystem Technology Assessment," 5030-555 Rev A, January 1983. We have also enclosed a copy of the most current technical overview of the project and technology, "Aluminum-Air Power Cell Research and Development: Progress Report," Proc. Electric and Hybrid Vehicle Sytems Assessment Seminar, Gainesville, Florida, December 15-16, 1983; LLNL Preprint, UCRL-90465 February 22, 1984

RESPONSE TO QUESTIONNAIRE

1. Performance Modelling

(a) Performance modelling is based on an equation interrelating battery weight (W_b, kg), peak sustainable power (P,kW), and peak energy yield (E, kWh):

$$W_b = 36(P/p) + 3.5\ (E/e)$$

where p is the peak power density (kW/m^2 of cell area) and e is the peak gross energy yield of aluminum (kWh/kg-Al). The coefficients depend on the choice of scale ratios (P/p = electrode area; and E/e = [illegible] of aluminum). The values of the coefficients are derived by dividing th[illegible]mponents of a battery into those which scale according to electrode area, and those which scale according to aluminum fuel mass. In Table 1.1 below, component weights are given for (arbitrary) E = 70 kWh, P = 31 kW, e = 5 kWh/kg and p = 7 kW/m^2.

Table 1.1

Component weights based on M3-2 wedge-cassette and crystallizer scale parameters: f_s =0.3 (solid fraction of seed in crystallizer by volume); a_p = 66.1 m^2/kg (area/weight ratio of seed); volume of electrolyte in cells = 133% of interelectrode volume for 2 mm gap.

Component	Basis	Weight(Kg)
1. Cells	M3 cell design; 1.1 g/cm^2; p = 7 kW/m^2	49
2. Cyclones	Krebs PC-1; cast in PVC	2
3. Electrolyte	Crystallizer and cyclone circuit	21
Electrolyte	Cell circuit and manifolding	14
4. Seed charge	Alcoa rate equation; C_{Sn}=0.06; T=70°C scaled for control at 2.7 M $Al(OH)_4$	18
5. Wedge	3° wedge angle	26
6. Misc.	case, impellers, air-pretreatment, drive motor and start-up battery	30
7. Aluminum	plates; 5 kWh/kg-Al	14
8. Water	for reaction and evaporation losses	32
9. Tankage	water, electrolyte, $Al(OH)_3$	3
	Total	209

The first six entries are treated as being proportional to electrode area (P/p); the last three are proportional to aluminum fuel mass (E/e). P and E should not be confused with the integrated energy or power delivered as these quantities depend on drive cycle. However, peak gross and net power yields are the same, as the auxiliary battery provides pumping energy during peak excursions. Net energy yield is equal to 96% of gross energy yield.

Best electrode combinations and cell dimensions indicate a peak energy e = 4.4 kWh/kg-Al and a peak power p = 6.5 kW/m^2 at temperatures of 60-70°C. These values are derived from the polarizations of best electrodes and thin interelectrode gaps. Current electrode research is motivated by the possibility of improvements to e = 6.0 kWh/kg-Al and p = 9 kW/m^2. The latter values may be taken as a difficult but potentially achieveable goal, combining successes in anode alloy and air-electrode research with advances in cell design. The former values are those used by Behrin et al. (Design Analysis of an Aluminum-Air Battery for Vehicle Operations; Final report to OVERD; UCRL-53382; March 1983), and are the basis for the present calculation. The latter were revised this year, and are the basis for projections for the full-performance electric vehicle in the 1990's time frame. These values are summarized below.

Table 1.2

Battery characteristic values for "Present" and "Full Perf. EV., 1990's time frame" calculations.

Parameter	Present	Full Perf.EV
Peak-energy yield of Al	4.4	6.5 kWh/kg
Peak sustainable surface power	6.5	9 kW/m^2
Open circuit corrosion	0.12	0.01 kA/m^2

Table 1.3

Data for Question 1. Battery weights, peak power, and power characteristics for E = 50 kWh and P = 50 kW.

	W_b kg	Peak Power W/kg	Specific energy (Wh/kg) vs Rate (W/kg) 20	60	80	100	157	200	218 W/kg
1. Present	317 kg	157	147	158	158	151	126	--	--
5. Full Perf. EV	229 kg	218	218	204	196	192	--	164	145

(b) The 30-second peak specific power capability is independent of the state of charge (i.e., remaining quantity of limiting reactant, aluminum or water). Consistent with current cell and electrode technologies, the peak power is associated with 6.5 kW/m^2, and is not decreased by system operation power which is delivered by the auxiliary battery (under peak power conditions only.) Full-performance is consistent with 9 kW/m^2.

2. Cost Projections

Manufacturing cost of an aluminum-air battery designed for Al-air-only (i.e., non-hybrid) vehicles is estimated to be approximately \$32/kW-peak-sustainable-power, for "present" characterisitcs (6.5 kW/m^2). The cost scales with peak power rating, and should become 23 \$/kW-peak-power if the Full-Performance value, 9 kW/m^2 is achieved in practical cells. (That is to say, nearly all battery components scale with electrode area, which is inversely proportional to peak power density.) The cost assumes present battery characteristics as described in the report, "Design Analysis of an Aluminum-Air Battery for Vehicle Operations," E. Behrin, et al., LLNL Report UCRL-53382, March 18, 1983 (Final report of work undertaken for OVERD).

Although design specifics and electrode performance objectives have changed radically since publication of Behrin's report, such changes have resulted in simplification of battery subsystems. Specifically, the sealed parallel-plate cell-stack design described in the report has been replaced by the gravity-fed wedge-cells which have no flexing or moving mechanical parts and are unpressurized. The rotating drum filter/separator has been replaced by a single stationary vessel equipped with hydrocyclone separators of commercially-available designs. The essential operating characteristics of wedge cells and hydrocyclones have been verified experimentally and are reported in UCRL-90465.

3. Technical Support for Projections.

Discussion on Cost Projections and Electrode Improvements

Electrode performance estimates. (See also answers to questions 2 and 3, below.) The cost of any fuel cell is generally proportional to the surface area of the cathode and inversely proportional to the surface power density of the cell. Power densities in excess of 10 kW/m^2 have been achieved using unalloyed aluminum and air-depolarized electrodes in cells tested at Hoppeka Battery Company (Brilon, West Germany) at high temperatures (80°C or above) in the more conductive KOH solutions.

The "present" open circuit corrosion is routinely achieved with unalloyed aluminum; and also with certain alloys developed on a proprietary basis for Eltech Systems by OSU. The "EV" value for open circuit corrosion has been approached with the use of a NaCN corrosion inhibitor (0.01 M NaCN, 4M NaOH, T=40° C) in combination with certain alloys; here o.c. corrosion was 2 mA/cm^2 and fell below the limit of detection (ca. 0.5 mA/cm^2) at -1.6 V vs Hg/HgO; this result and homologous compositions may be patentable and should not be disclosed.

Life-cycle advances in the air electrodes catalyzed with macrocyclic catalysts were reported in UCRL-90465; currently drive-cycle life stands at about 1500 cold startups, an increase by an order of magnitude since the start of the program. Aluminate and aluminum-trihydroxide have been found to be catalysts for peroxide decomposition. Parallel tests in electrolytes baring aluminate and pure caustic electrolytes indicated longer lifes in the former. We believe that 3000 drive cycles (4 year road life) might be a reasonable goal; however, current attention at Eltech Systems, Inc. is focused not on extension of cycle life but on developing continuous processes for cathode mass production.

The standard drive cycle life consists of a series of constant-current plateaus between 1- and 6 kA/m^2 followed by standby at open circuit. Drive-cycles are designed to imitate a typical trip, 750 of which are covered in single year. Failure is associated with processes occuring within the first hour of shut down and hold on open circuit. The deterioraton is associated with a loss of catalytic activity, possibly the result of corrosion and isolation of carbon particles. The process apparently is self-inhibiting, and does not continue beyond the first hours of standby. Life extension is being sought through the use of corrosion-resistant carbons, heavier loadings of macrocyclic catalysts, self-regenerating catalysts (e.g., sparingly-soluble catalysts), improved wet-proofing agents, and improved mechanical support of the carbon-Teflon matrix.

Beyond any doubt, the area of greatest potential improvement is that of the anode-alloy/ electrolyte/ operating-temperature combination. With the exception of work performed by Reynolds under subcontract to LLNL, almost no research has been undertaken under DoE sponsorship. This area is being actively pursued by privately-sponsored projects by Eltech (at OSU); Alcan, Ltd. (ca. \$1M/y); at Atlantic Richfield (Harvey Ill.), ca. \$300K/y; and at General Motors (Warren, MI), undisclosed level. A small research program is believed to be conducted at South African National Research Center.

Generic approaches to the modification of energy yield and power include:

(1) Vacancy injection or lattice modifications. Use of trace (100 ppm) loadings of dissimilar-valence metals (Si, V, Ga) to alter the vacancy concentration in either the metal or oxide sublattice of the anodic surface film; hence alteration of the resistance of the film to the mobile ion (either Al or O) Broad classes of lattice expanders" or "lattice contractors" have been identified and discussed in the literature; these effect changes in mobility of the aluminum or oxidic species.

(2) Selective inhibition of the water-reduction reaction. Use of metal-phase or electrolyte-phase poisons for the water-reduction mechanism responsible for hydrogen evolution. Examples here include Sn, CN, P, Tl, and Pb. Often these materials tend to deposit on grain boundaries or inclusions having low overpotentials for H_2 evolution.

(3) Complexing or segregation of undesirable materials. Certain materials are used to segregate undesirable impurities common to low-cost smelter-grade aluminum. For example, Mn is used to form intermetallic clusters of Mn, Fe, and Al, which have greatly reduced activities from the standpoint of water reduction. The alloy developed by Reynolds was found to yield 85% of the energy of RX808, yet cost essentially the same as 5A base smelter metal. (See UCRL-90465.)

(4) Alteration of thick surface layers. The addition of Mg to the alloy has an indirect by profound effect on coulombic efficiency. Surface layers of insoluble, loosely-adherent MgO may entrap electrolyte and create a local electrolyte composition different from that of the bulk. Gallium may effect a reduction in anode surface film adherence. The combination of Mg and Ga is responsible for the high surface power density and coulombic efficiency of RX808. This is currently under investigation by Eltech under subcontract at OSU.

(5) Use of high purity metals. Iron, being deleterious to coulombic efficiency, can be largely removed from Hall-Cell metal through control of coke, alumina, cell lining, and plant practices. (For example, a iron pick is used to break the cryolyte crust each time alumina is added to the cell; it readily dissolves in the melt.) Reynolds assessed the increase of cost associated with achieving 0.04% Fe levels; results are reported in UCRL-90465.

Production of high purity Hall cell metal may be unnecessary. Current processes exist for the partial crystallization of highly pure metal from a molten stream combining the separate outputs from a large array of Hall cells. This "single pass zone refining" might be used to produce highly pure metal for battery fuel applications as a byproduct of a large plant. Currently there is very little market for high purity aluminum other than experimental uses or "sweeteners" for certain aircraft alloys.

Advanced processes for aluminum production (likely to be introduced within the early 1990's) do not have the same impurities or levels of impurities associated with Hall Smelter. The Alcoa Smelting Process utilizes a vapor-phase separation of $AlCl_3$, and uses no dissolving iron parts; the process incidently consumes only 8.3 kWh/kg-Al. The Mitsui carbothermic reduction process, now in pilot investigations, distills Al from a Al/Pb melt used to extract the metal from alumina/carbon brickets. The iron content is well below that of common smelter-grade aluminum.

In all, it should not be assumed a priori that a cheap aluminum alloy must be based on metal of current commercial purities.

(6) Alterations of electrolyte composition and operating temperature. One-half of the resistance of the aluminun-air cell (3.2 mm spacing) is associated with resistance of the NaOH electrolyte in the interelectode gap. Electrolytes of higher conductivity (KOH or KOH/NaOH) are being investigated, together with interelectrode gaps below 2 mm to decrease this loss. Cell power increases by 20% per 10 °C increase in temperature--as expected for an electrolyte resistance. Increase of operating temperature from 60 to 80 °C should incease surface power density from typical values of 6 kW/m^2 to nearly 9 kW/m^2, when electrolyte resistance and electrode polarizations are taken into account. The limiting factor in temperature increase is water-reduction rate, which also shows an Arrhenius dependence on temperature. The reader is reminded that advances in coulombic efficiency have their primary benefit, not in increased energy yield (coulombic efficiencies are generally above 90%), but in increased power density.

Anode research will receive the major emphasis following successful operation of full-scale, integrated batteries (five-cell modules) at the end of the current calendar year. Alcan has reported to us the existence of a number of new alloys of performance superior to either pure aluminum or RX808 models, including new classes of alloys not requiring electrolyte corrosion inhibitors. A cell operating at 2 V is claimed. This work is not done under DoE auspices and exact compositions were not disclosed to us. Hence, I an unable to independently confirm these claims, although I have no reason to believe that they are exaggerated.

Component Improvements. The use of hydrocyclones of advanced design has resulted in a major simplification of battery design as well as cost reductions. The hydrocyclones were developed by Krebs Engineers for

industrial applications. The units tested in our laboratory with the experiments on integrated cells and crystallizers feature involute-spiral entrance chambers which greatly increases operating efficiency. Two or three units would consume about 1% of gross battery power output; power consumption can be further reduced by placing cyclones in series to stage the particle separation.

Air Electrode Cassettes. The use of air-electrode cassettes which are individually removable and replaceable relax quality control constraints on the air electrodes. Incipient failure or deterioration can be detected, and the electrode may be replaced without loss of the stack. (This is not practical with fuel cells because of the 5-6-fold increase in gas-diffusion electrode area per unit of gross power, and the corresponding increase in the weight of the supporting cassettes.)

Air electrode cost projections of $100/m^2$ assuming large scale production and semi-automated continuous fabrication processes (replacing current small-scale batch processes) and non-precious metal catalysts. This goal is consistent with those of many air-electrode developers. The cost includes a stamped or injection-molded polypropylene holder (cassette). Note that the replaceable unit does not necessarily include electrolyte manifolding as in the Reference Cells. Solution side current collectors need not be replaced along with the cassettes and are expected to last the life of the vehicle.

4. Energy Balance

Startup and shut-down. Current approach to shut down involves draining electrolyte from the cells into the crystallizer, followed evaporation of electrolyte adhering to the anodes. Using the latent heat of the anode mass, this is accomplished in a few seconds. Tests on 50-cm^2 cells show that the loss approaches a steady-state value of 1.2 g/m^2-shutdown. For $e = 4.4$ kWh/kg, $p = 6.5$ kW/m^2 and 730 shutdowns per year, this constitutes a loss of 29 kWh/year: or 40 Wh per shutdown for segments 2 and 4. For $e = 6$ kWh/kg-Al and $p = 9$ kw/m^2, the loss per shutdown is also about 40 Wh. This effect is certainly dependent on alloy composition and electrolyte composition, and passivation of the aluminum cannot *a priori* be expected to occur. It will be difficult to satisfy this constraint while achieving the high energy yield and high power density levels. Nevertheless flash evaporation and induced passivation is one of the constraints that should be observed in our alloy development project.

Shunt currents are generally not a problem as we are not concerned with redistribution of metal upon prolonged cycling. The resistance of the electrolyte paths between adjacent cells is currently on the order of 6 ohms, and could be reduced further; cell-cell voltage difference is about 1.6 V; current delivered per cell is 120 A. Therefore loss is about 0.2%.

Parasitic losses are associated with the hydrogen evolution reaction. For model electrodes this ranges from 2-25 mA/cm^2 on open circuit and falls off with increasing current density. Segments 1-3 contain 25 s each of standby, resulting in losses of 1.5-19 Wh/segment, for EV and present calculations. Segment 4 contains 50 s standby, resulting in a loss of 3-36 Wh/segment for EV and present calculations.

Self-discharge. (Answered separately under parasitic and shut-down categories).

Thermal loss. N/A under specified operating conditions and cycles.

Charge efficiency. N/A

5. Life Considerations

As anodes are intended to last only one cycle, life cycle is limited by cathode failure. Current life cycles of 1500 have been achieved, and actual life may be longer: the most recent tests failed because of computer malfunction, not cathode failure. Very little statistical data is available as identical electrodes have been tested in insufficient numbers.

Polypropylene is indefinitely stable in caustic aluminate. PVC is effectively stable as well, and can be extended with alumina.

I am not too concerned that scale formation will be a serious problem in this battery, although we are currently planning experiments to investigated this. If growth mechanisms apply to the development of scale on the inside of the crystallizer, the mass of the scale cannot be more than the annual throughput of hydrargillite (ca. 1500 kg) multiplied by the ratio of vessel surface area to seed-surface area ($1\ m^2/1500\ m^2$), which indicates a film growth of 0.4 mm/year; this is trivial. While scale formation may entail agglomeration or porous material at an order of magnitude higher rates, our colleagues at Alcoa and more recently at Alcan, Ltd. tell use that convection, vibration (flexing of walls) and non-stick walls reduce scale formation or adhesion. Coating critical parts (valves and impellers) with Teflon may be necessary. An ice-cream scrapper may be useful in the crystallizer vessel.

Again, air electrode cassettes which form the body of the cell in contact with electrolyte are designed to be individually replaced upon failure or malfunction. Electrolyte residence is to brief in the cells given normal driving patterns for scale buildup to be a problem. We do not expect solution-side current collectors to constitute a failure mechanism, as these are cathodically protected by the aluminum. Pumps and valves are the likely sites of failures.

6. Other Operational Characteristics

(a). Special charge requirements. Over-discharge results in a gradual, non-destructive loss of power. This would be accompanied by the gradual withdrawal anode wedge into the cell. As the anode falls at a rate of about 1.2 micrometers/s at cruise velocities, one would travel 140 miles per cm of fall, accompanied by an 8% loss of power.

Cell equalizing will be required at a frequency which we cannot now estimate. This is accomplished by adding fuel plates of different heights to the various cells. The cells share a common electrolyte through exchange with the crystallizer; hence no individual balancing is required.

Periodic complete discharge is not required.

(b). Maintenance. Refueling is to be accomplished by tap water additions (250 miles) and aluminum additions (at frequencies of 100-3000 miles) by the vehicle owner in his own garage. Aluminum fuel plates could also be vended by machines or service stations. Cells are designed for refueling by adding

plates of appropriate height to a dry chamber above the cell; the wedge is not disturbed by this operation, nor is contact to be expected with electrolyte or electrolyte-wetted components. Hydrargillite withdrawals at frequencies of 250-500 miles are required. The hydrargillite is in water-washed, drained form. Again this may be done either in the owner's garage or at central stations (in a manner commercially analogous to collection of aluminum cans). In the long range, service stations might compete with owner servicing.

Battery refurbishment has not been explored. Possibility of refurbishing the air electrodes by doping with a sparingly soluble macrocyclic catalyst has been discussed. We do not regard this issue as premature.

7. Packaging Flexibility

Overall specific gravity is about 0.6. Nevertheless we do not consider volume to be a limiting factor for three reasons.

(1) Much of the volume of the battery is in the form of water and product tankage, which can be shaped to fit the contours and placed in parts of the vehicle not normally used (e.g., doors, underpan spaces, structural tubes, spaces under the seat, etc.). Without any special care, Alcan was able to fit the entire quarter-scale battery (based on Behrin's 1982 design), motor, and motor controller within a quarter-scale Chrysler for the SAE conference. The only component of rigid design is the cell stack, which occupies 180 liters per 100 cells. An efficient crystallizer/separator design may require a specially allocated volume.

(2) The open spaces required for heat transfer in the aluminum-air battery are located within the cassettes in electolyte return channels and in air-manifolding channels. Heat transfer interfaces for batteries with exothermic charge or discharge reactions generally coincide with the surface of the battery box; hence the volumes are likewise required but are not counted in specific gravity. For this reason, a volume specification cannot be applied uniformly to these different configurations.

(3) The apparent volume power density limitation is the consequence of over-constraining the JPL vehicle baseline. If volume were a problem, it is all too easy to buy additional space by raising the hood or choosing a longer car. Raising the hood two inches buys about 140 liters of additional volume (1/3 the volume of the "present" battery!).

(c) Relative placement considerations allow some flexibility in using tankage to absorb collision impact, or to absorb caustic spills.

(d) The battery scales according to power rating. A 10 kWh battery is immaterially different from a 70 kWh battery of the same power: the only differences are size of the water and product tanks and the mass of aluminum.

COMMENTS ON "ADVANCED VEHCLE SUBSYSTEM TECHNOLOGY ASSESSMENT"
REPORT: 5030-555 Rev.A

Some updating of this material is warranted. Comments are by section.

Battery Description. Regenerative breaking is quite appropriate for this battery, as it can offset or eliminate the system power requirements which (except under peak power conditions) come from an auxiliary secondary battery. Moreover, some peak shaving power can be supplied by regenerative breaking with an appropriately designed battery which could provide auxiliary power as well. I understand that JPL is taking this into consideration in the revised modelling, this important option should be included.

The hydrargillite is washed and drained to yield $Al(OH)_3$, not alumina.

The refueling time estimate by Interplan (15 minutes for aluminum plate addition) was not updated for the wedge cells. Here plates are dropped into individual slots on the battery box, and refueling should be comparable to automotive refueling, i.e., about 5 minutes.

Performance characteristics. Possibly, the water of reaction would be stored within the hydrargillite container, as the product powder is about 45% air.

Energy Efficiency. The production of aluminum is not inherently inefficient: aluminum can be electrowon from the melt under conditions approaching reversibility. Most older Hall smelters were designed for maximum production and not energy efficiency. Until the last 10-15 years, the cost of energy did not appear in the equation for economic optimization of cell design (although energy costs dictated geographical location of the cell). Currently, commercial Hall cells have been operated Pechinney St. Lucienne at an average rate of 11.3 kWh/kg. The Alcoa smelting process in large cells consumes 8.3 kWh/kg of electrical energy. Finally, a consortium of Japanese industries is currently developing the Mitsui carbothermic reduction process which consumes no net electricity yet produces a highly pure product. Commercial application of at least one advanced process is highly likely in the 1990's, as the aluminum industry is evolving under the same energy-economy pressures which motivate electric vehicle development.

Advanced electrochemical processes for aluminum production indicate electrical efficiencies (utility to battery terminals) of 51-72%, based on 4.3- and 6 kWh/kg-Al peak yields. Carbothermic reduction processes would reduce energy consumption still further, and result in aluminum being among the most efficient of all uses of primary coal energy in transportation. We believe it is unwarrented to (1) assume major advances in electric vehicle battery technology while (2) assuming no advances in aluminum smelter technology.

There are other differences between secondary battery and electrochemical fuels. Unlike the use of distributed electricity, aluminum smelters pay relatively little electricity "distribution" losses, and energy loss of transporting metal and product is small compared to electrical distribution. Moreover, the practice of locating aluminum smelters in remote power sites

(James Bay or N. Australia coal districts) or with very large utilities (Parana River) allow aluminum production to "scavenge" energies of lower than average economic value. There is simply no basis for attempting to cross-compare energy systems based on so radically different energy sources and economics as the aluminum industry and distributed urban electricity.

Charge efficiency The value of 36% for electrical energy generation efficiency does not derive from an assumption of on-site electrical generation and use. Rather it is based on the fact that the industry is a user of base-load energy, the production of which is more efficient than that of distributed urban electricity, which includes contributions of peak-shaving plants. (Despite the mythology, there is no a priori reason for assuming the consumer will charge his vehicle late at night unless he is given an economic incentive for doing so.)

Cost Projections. The estimated cost of the air electrode cassette (electrode and minimum supporting structure) is $100/m^2$, assuming a macrocyclic catalyst and continuous fabrication processes. Platinum is not under consideration for a vehicle catalyst because of higher cost, poorer polarization and life-cycle values, and limited availability. On-road cycle-life is not expected to be below two years (1460 cold-startups) and a 1990's projected level of 3000 is a reasonable goal for electrode development.

Conclusions. Again, the apparent problem arising from the low specific gravity of the system is an artifact of JPL vehicle baseline assumptions and the result of Al/Air battery design considerations (which make use of a large internal air volume for heat transfer). With a different choice of vehicle, no problem arises (except for modellers!).

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ALUMINUM-AIR POWER CELL RESEARCH AND DEVELOPMENT
PROGRESS REPORT

John F. Cooper

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ALUMINUM-AIR POWER CELL RESEARCH AND DEVELOPMENT: PROGRESS REPORT*

John F. Cooper

Abstract

An aluminum-air battery is under development with the objective of providing an electric vehicle with the range, acceleration and rapid refueling capability of common automobiles. From tested refuelable cell designs, a wedge-shaped cell was chosen for mechanical simplicity and for its capability of full anode utilization and rapid partial- or full recharge. The cell uses tin-plated copper tracks (trianguar cross section) to maintain a constant interelectrode separation and to collect anodic current. Rectangular slabs of aluminum enter the cell under gravity feed and gradually assume the wedge shape during dissolution. The feed is constant and continuous and tin/aluminum junction losses are 7 mV at 2 kA/m^2. A second generation wedge cell has been developed which incorporates air- and electrolyte manifolding into individually-replaceable air-cathode cassettes.

A prototype wedge cell using replaceable cassettes was operated simultaneously with a crystallizer, which stabilized aluminate concentration and produced a granular aluminum-trihydroxide reaction product. Electrolyte was circulated between cell and fluidized-bed crystallizer, and particles of sizes greater than 0.015 mm were retained within the crystallizer using a hydrocyclone.

Air electrodes have been tested over simulated vehicle drive cycles which include a standby phase in cold, supersaturated electrolyte. Electrodes using advanced sintering and wet-proofing techniques and catalyzed with a non-noble metal catalyst (CoTMPP) have been operated for over 1400 drive-cycles (corresponding to a two-year road life).

Fuel costs of $1.72/kg-Al (installed) were estimated on the basis of model alloy production and distribution costs, leading to a projected operating cost of 8-10¢/mile, depending on alloy and vehicle drive-train efficiencies. Unalloyed aluminum yields a peak of 4.5 kWh/kg, while an advanced industrial Hall Process and the pilot-plant Alcoa Smelting Process have electrical energy consumptions of 11.3- and 8.3 kWh/kg, respectively. The significance of energy-use estimates for the 1990's and beyond is discussed.

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1.0 Objectives

The refuelable aluminum-air battery is being developed for electric vehicle applications because of its potential for providing the range, acceleration and refuelability of common automobiles.[1,2] Aluminum as a vehicular fuel cannot compete with gasoline derived from conventional sources of petroleum and selling at today's prices. Nevertheless mechanical refuelability, high specific energy and power, and the energetics of aluminum production suggest a route to conserving the quality of transportation in an era of petroleum scarcity and price increases brought about by political or natural causes.

The use of aluminum as a recyclable electrochemical fuel would be roughly comparable in energy use and cost to synthetic liquid fuels derived from coal.[3,4] However, it would avoid the essential dependence on carbonaceous primary resources and the environmental degradation associated with the massive conversion of coal. The production of aluminum as such does not presuppose particular primary energy resource, a strategy for its conversion, or a specific geographical location for industrial production. The metal is light enough to be transported trans-oceanic distances without incurring prohibitive freight costs--thus bringing a national fleet of vehicles access to a world production market.[4,5] The existence of a large aluminum industry is an additional advantage. Projected aluminum demand in the 1990's is large enough --roughly 12 Mtonnes/y--to absorb the gradual introduction of a million aluminum-air vehicles (0.58 Mtonne/y). Finally the aluminum industry will evolve within the time frame of possible vehicle introduction as a result of rising electricity costs. This expectation requires that we consider the impact of new industrial processes that are operating now or likely to be introduced in the next decade.

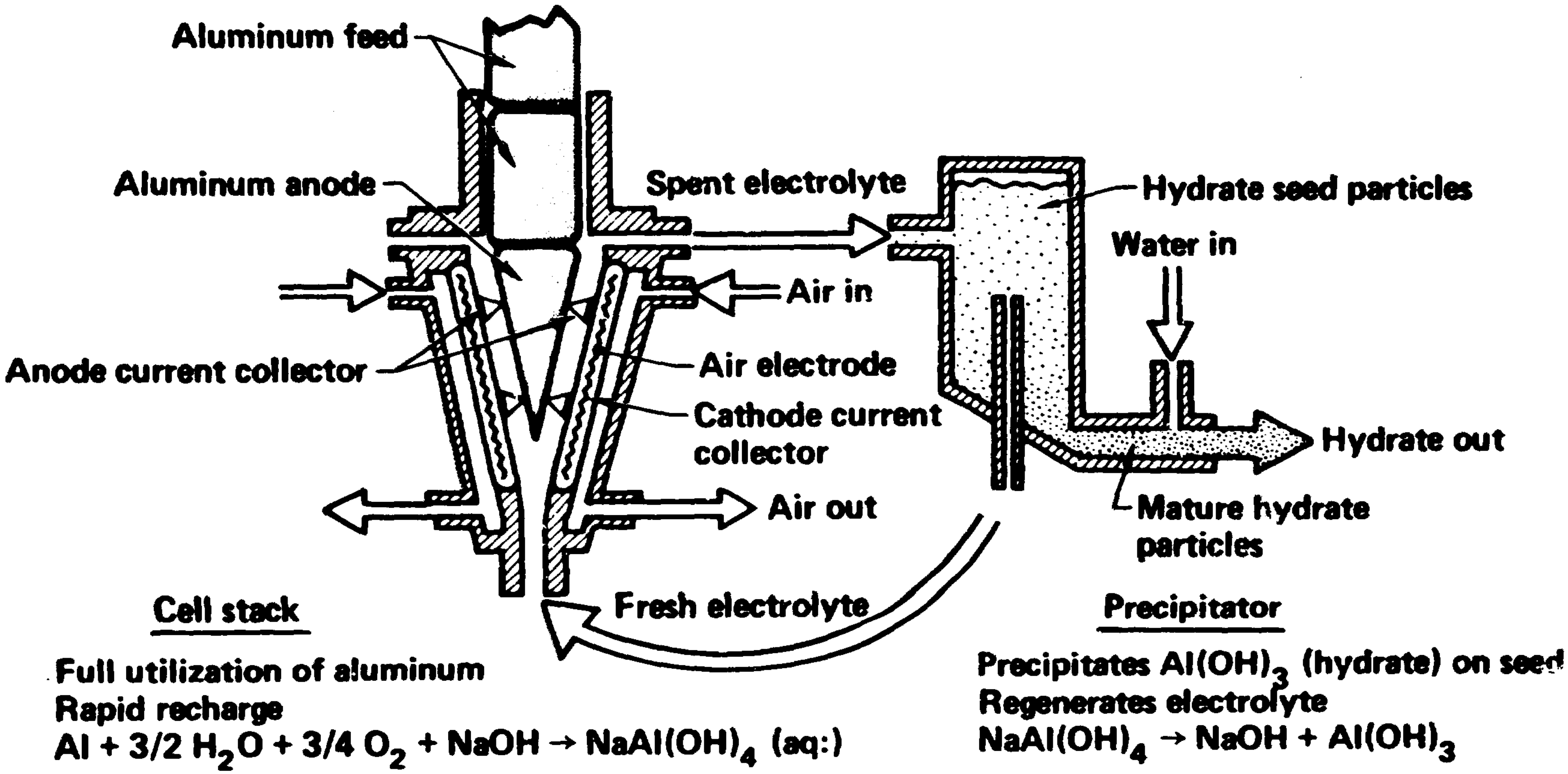

Figure 1. The aluminum-air battery consists of two essential components: a galvanic cell stack of wedge-shaped cells and a fluidized bed crystallizer. Current collection in the cell is effected by parallel tracts of copper which make contact with the aluminum at the electrolyte interface

2.0 Background

Two basic components of an aluminum-air battery--cell and crystallizer--are shown in Figure 1. We have developed a wedge-shaped cell (based on a concept proposed to A. Despic)[6] with the objective of full utilization of the aluminum fuel. The cell consists of two air-cathode cassettes held at an angle of 3 or 6°. On the surface of each cassette are metal tracts serving as cell separator and anode current collector. The aluminum dissolves on the faces opposite the cathodes and maintains a wedge shape as it is consumed. Retangular-slab fuel plates gradually assume the wedge shape as they enter the cell under gravity feed.

Refueling is accomplished by addition of the rectangular plates to a dry chamber above the cell and tap water to a storage tank. Plate addition is simple and safe enough (from the perspective of the refueler and the fragility of the cell) to suggest refueling by the owner in his own garage. A year's supply of aluminum plates would occupy 0.21 m^3 (7 cu ft), while a month's accumulation of reaction product would occupy about 0.12 m^3 (i.e., about one standard 35 gallon container).

Individual cassettes (Figure 2) may be removed and replaced upon electrode disfunction or failure. The use of cassettes reduces cost and quality control requirements relative to multiple-cell stacks which cannot easily be disassembled.

The predominant electrochemical reaction in the cell is:

$$Al + 3/2\ H_2O + 3/4\ O_2 + NaOH = NaAl(OH)_4 \qquad (1)$$

Also hydrogen gas is evolved at the anode as a side reaction at a rate depending on composition of the anode alloy, aluminate concentration,

temperature, and the use of corrosion inhibitors (eg., sodium stannate). This reaction does not generally exceed 5-10% of the rate of aluminum dissolution and coulombic efficiencies exceeding 97% are obtained with unalloyed aluminum under time-averaged discharge rates of 2 kA/m^2. Catalytic recombination (or controlled combustion) of hydrogen and oxygen in the air stream over the cell will be required for safe vehicle operation.

The crystallizer catalyzes the decomposition of the supersatuated caustic-aluminate to form granular aluminum trihydroxide in the hydrargillite polymorph:

$$NaAl(OH)_4 = Al(OH)_3 + NaOH \qquad (2)$$

As hydrargillite is an intermediate feedstock of the aluminum industry, reaction (2) suggests the possibility of recycling to produce either aluminum or alumina products. (Explicit recycling to produce aluminum fuel plates is conceivable but not necessary until the vehicle fleet becomes large enough to seriously perturb the alumina market).

The crystallizer is a fluidized bed charged with about 18 kg of hydrargillite particles of maximum size, 50 micrometers. As shown in the system flow chart of Figure 3, a hydrocyclone has been chosen as the means of separating the relatively clear caustic aluminate electrolyte from the exit stream of the crystallizer. The power required by the hydrocyclone is not more than 1% of the gross battery power for a separation cut point of 15 micrometers. This separation would confine 99+% of the hydrargillite to the crystallizer. The other components are provided for selectively removing, washing, and draining the mature hydrargillite particles (50 micrometers and larger).

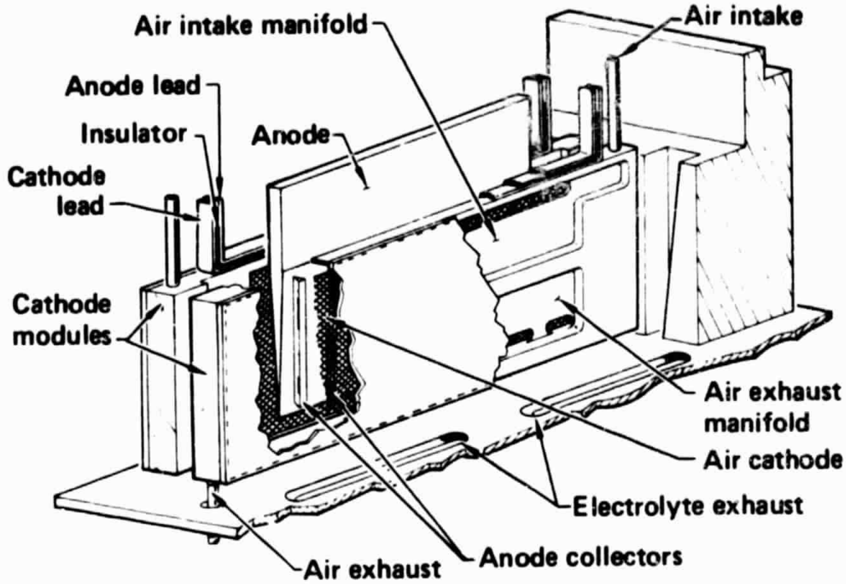

Figure 2. Wedge-shaped cells are formed by positioning two air-electrode cassettes at an angle of 3-6°. Individual cassettes can be removed and replaced following disfunction or failure.

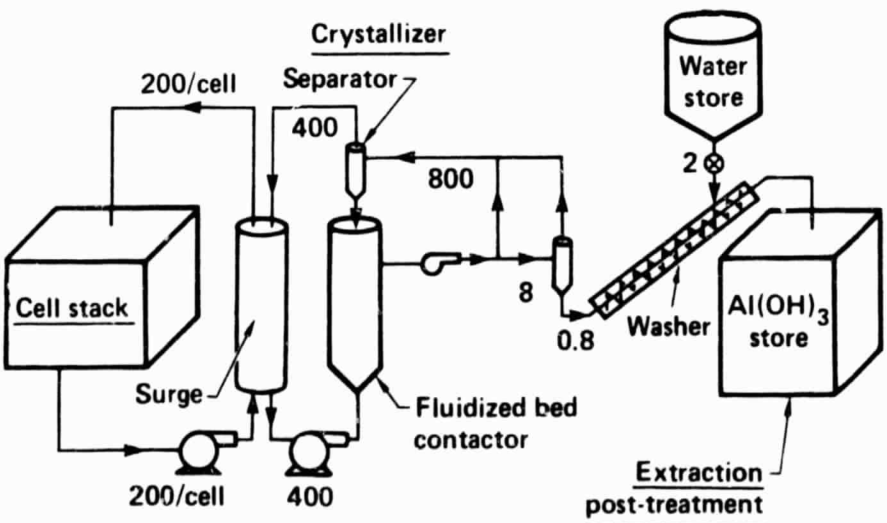

Figure 3. Electrolyte is circulated between cell stack and crystallizer. Particles are retained in the crystallizer by means of a hydrocyclone separator, which may also be used to selectively remove mature particles for storage. Numbers indicate approximate volumetric flow rates (ml/s).

C-4

3.0 Technical Approach

Early in the program we adopted a development strategy which split the problems of battery process and configuration development from those associated with development of cost-effective and efficient electrodes.[7] This decision reflected the essential independence of the technical problems facing each of these areas. Early phases of the program addressed problems associated with refuelable battery hardware and processes. Model electrodes were used for testing refuelable cell designs, developing precipitation models, and integrating cell and crystallizer processes. The model anode and cathode were taken, respectively, from a torpedo propulsion battery and an advanced chlor-alkali process using an air-depolarized cathode. (Currently, unalloyed aluminum is used as a model anode.) These are not necessarily advanced as commercially feasible fuels. Progress in the development of the battery is shown in Figure 4. Recently we have integrated a 600-cm^2 prototype cell (wedge configuration) with crystallizer and hydrocyclone separator, and operated these over conditions anticipated in the vehicle. This allows accurate determination of the weights of a full scale vehicle battery. Currently, support auxiliaries are being developed. A fullscale vehicle prototype battery design will be developed by 1986.

This year we have chosen a prime industrial contractor: Eltech Systems, Inc.--formerly Diamond Shamrock Company--in association with the Aluminum Company of Canada (Alcan, Ltd.). Eltech will pursue development of the battery for commercial applications and place increasing emphasis on the development of commercially attractive alloys. The industrial partner contributes to the support of the program in return for foreground patent rights. In addition, Alcan carries on a larger internal program devoted solely to the proprietary development of alloys meeting the cost-constraints of

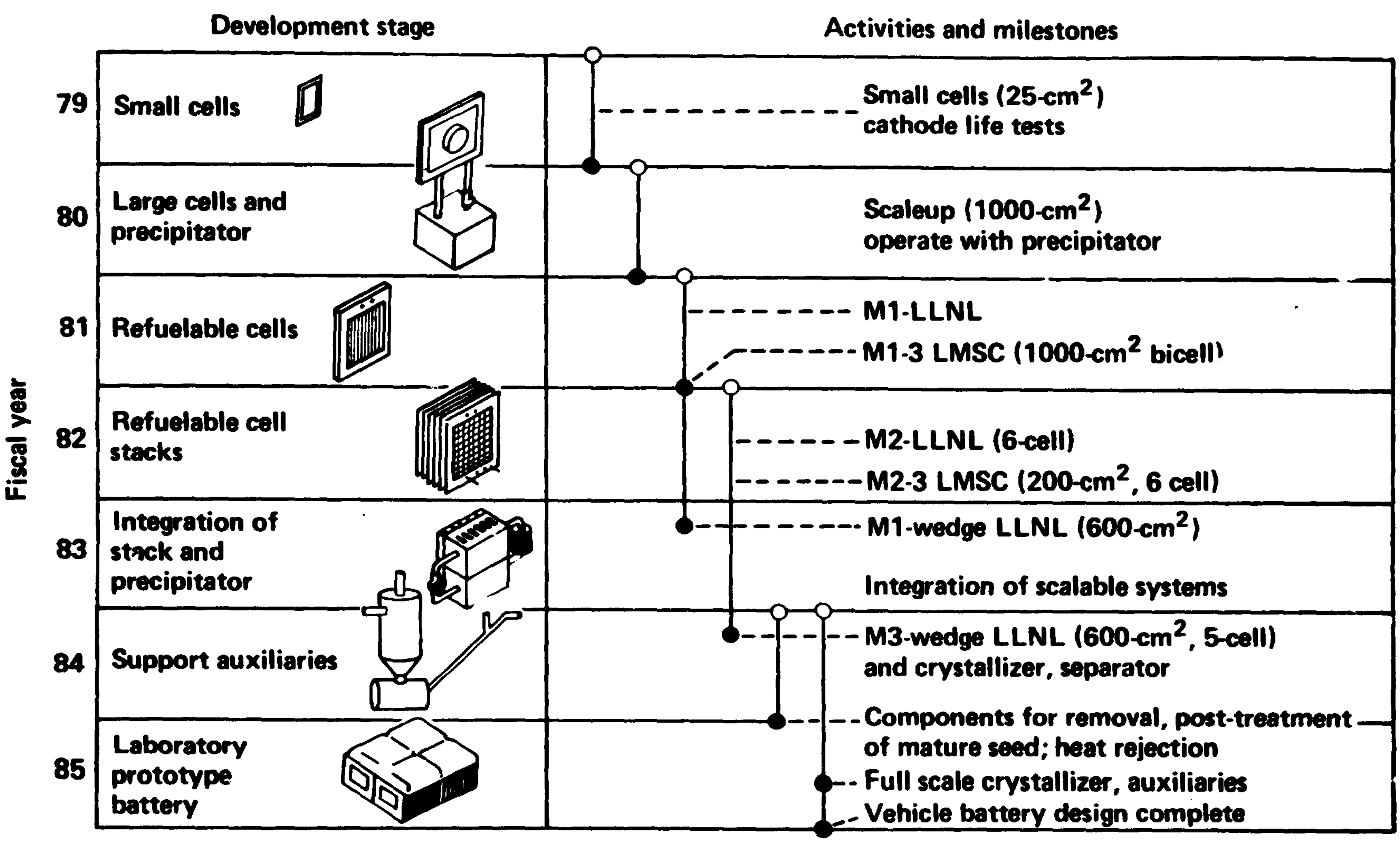

Figure 4. The aluminum-air battery technology evolved from single primary cells through rapidly-refuelable cell stacks and integrated cell/crystallizer/hydrocyclone systems. Current efforts include development of auxiliaries for withdrawal and post-treatment of mature hydrargillite.

vehicle applications. LLNL manages the program for DOE, Energy Storage Division. In support of the program we conduct process research focused on the integration of multicells, fluidized bed crystallizers, and hydrocyclone separators.

4.0 Technical Status and Problems

4.1 Cell and Cell Stack Research. The battery technology was developed in stages from small single cells to large refuelable multicell stacks without suffering a degradation of power or voltage, as shown in Figure 5. The voltage and power density curves were obtained with identical pairs of electrodes and operating conditions. The increase in power density attained with the M2 6-cell stack resulted from improvements in air distribution and cathode current collection techniques.[8] Figure 6 shows performance of a low gallium alloy and Diamond Shamrock Standard air electrode in cells with interelectrode separations of 1.5 mm.

A cutaway drawing of the M3-wedge cell tested over the last year is shown in Figure 2. High conductivity copper tracks (with equilateral-triangle cross sections) support the wedge and provide a permanent solution-side anode current collector. The cassettes of the test cell (Figure 7) weigh 1.1 g/cm^2 and the cell typically delivers a peak power of 5 kW/m^2. Figure 8 shows vertical displacement is continuous and constant, while the junction losses amount to 7 mV--about 0.2% of cell voltage.

We have optimized the current collection in these cells by determining the current distribution as a function of collector design. Figures 9 and 10 describe respectively the modeled cell resistance network and the corresponding current distribution.

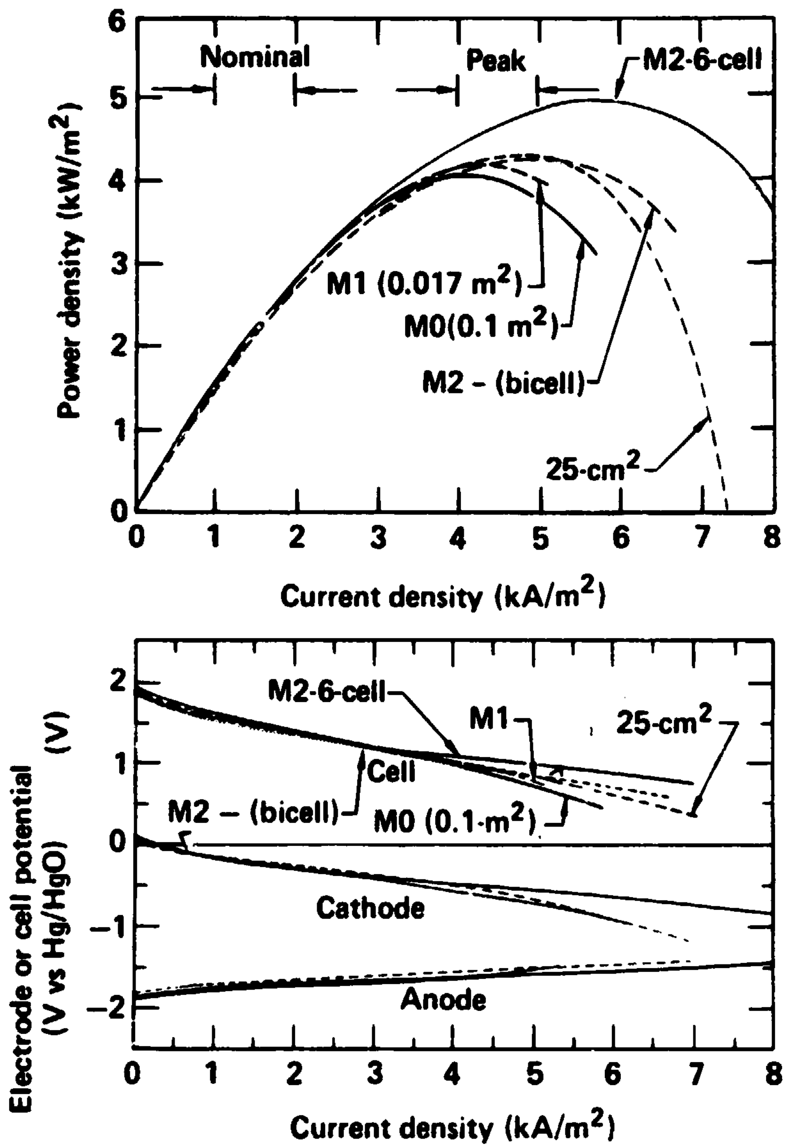

Figure 5(a). Surface power density based on medial cell area. RX808 and Diamond Shamrock standard air-electrode; 4M NaOH + 1M $Al(OH)_3$ + 0.06M $Na_2Sn(OH)_6$; 60°C. 5(b) Cell and electrode polarization (uncorrected for IR drop) for systems of 5(a).

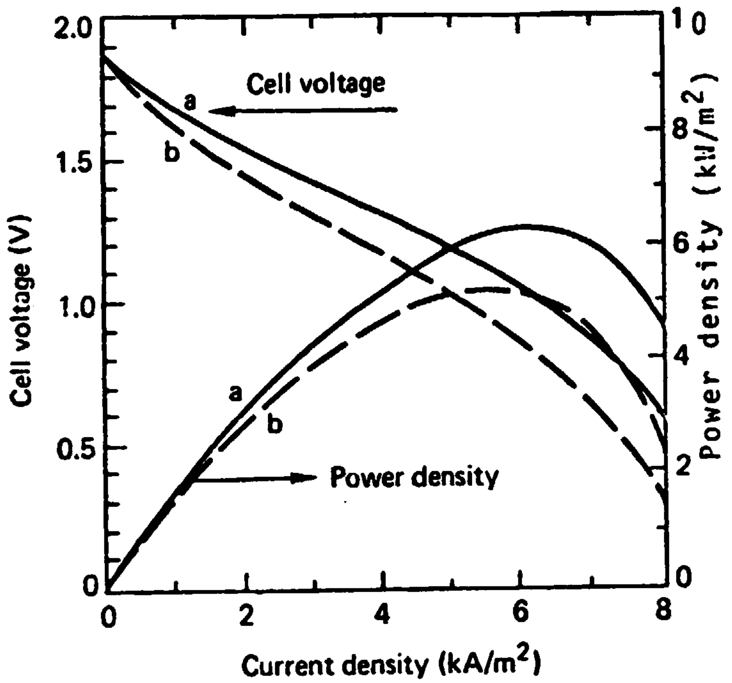

Figure 6. Polarization chracteristics of 25-cm^2 aluminum-air cell, using Reynolds alloy RX808-F and Diamond-Shamrock Standard Air Electrode. Electrolyte as in Figure 5. Operating conditions: 60 ^{o}C; 4M NaOH + 1M $Al(OH)_3$ + 0.06M $Na_2Sn(OH)_6$; flowing electrolyte, Re = 1000. Interelectrode gap: (a) 1.5 mm, (b) 3.2 mm.

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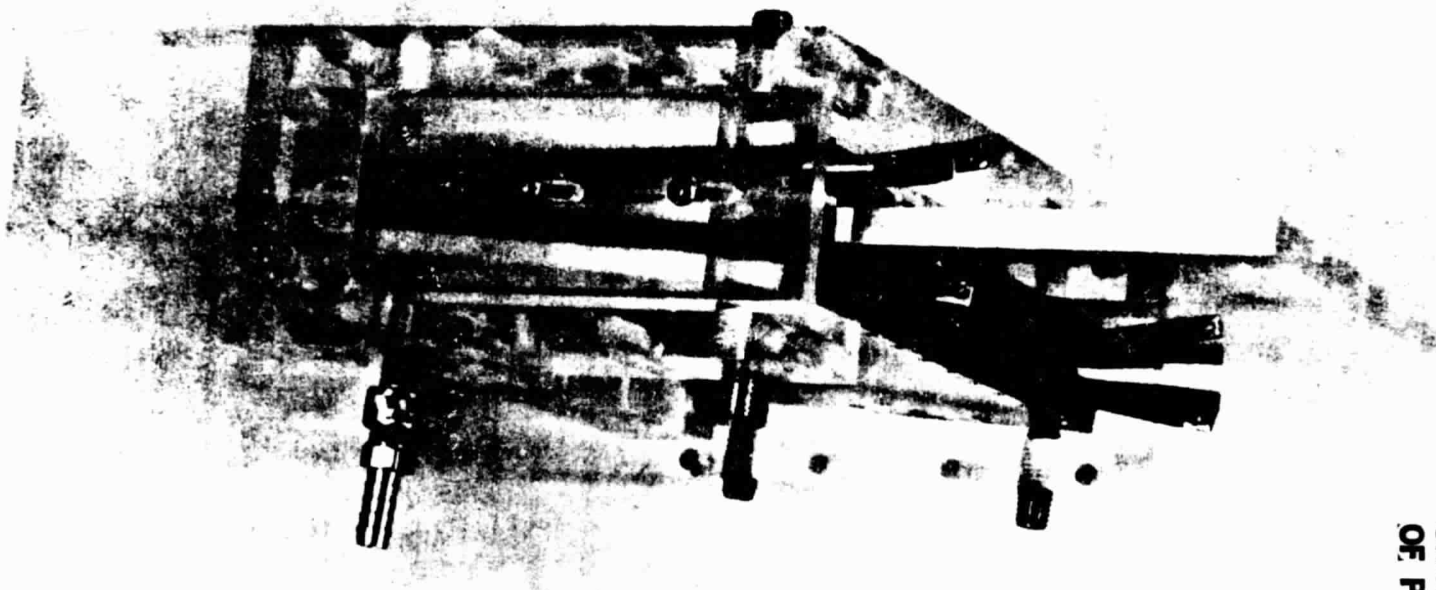

Figure 7. Wedge-shaped cell M3-1 consists of two replaceable air-electrode cassettes held in a slotted plexiglass tank.

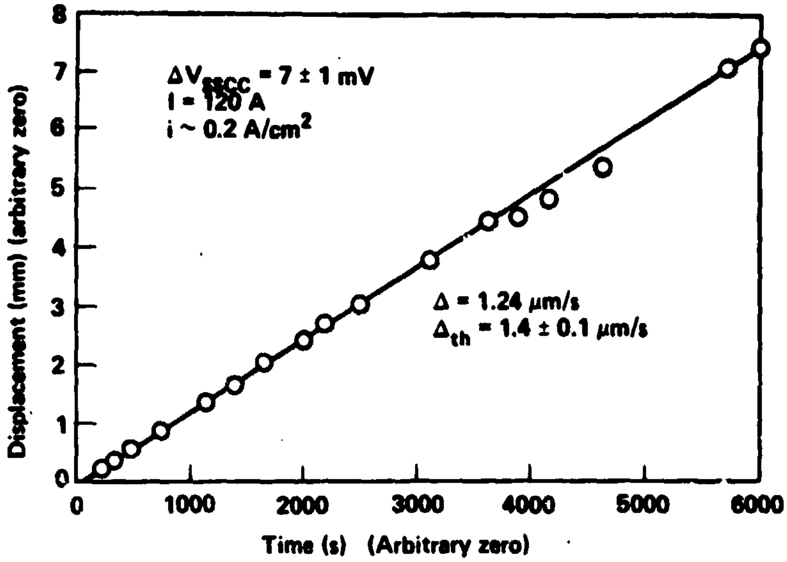

Figure 8. Displacement of the anode into the cell under gravity feed is continuous and constant at a rate of 1.24 micrometers/s. The theoretical rate of fall (1.4 micrometers/s) is calculated on the basis of idealized cell geometry and Faraday's law. Anode/SSCC voltage losses of 7 mV are small compared to the cell voltage (1.5 V) under these operating conditions.

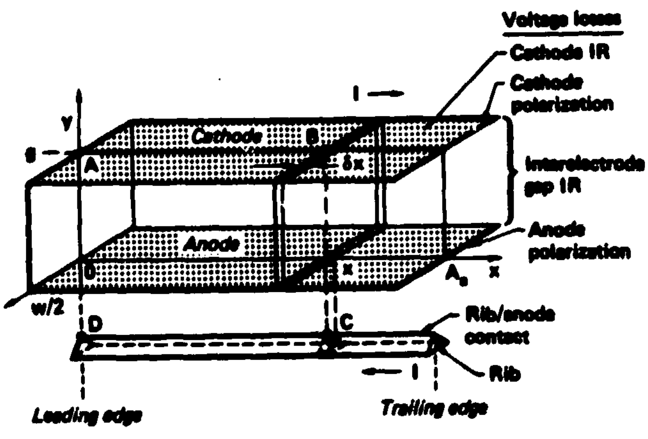

Figure 9. Network analysis of the wedge-shaped cell, M3, leads to the dimensionless current distribution equation discussed in the text.

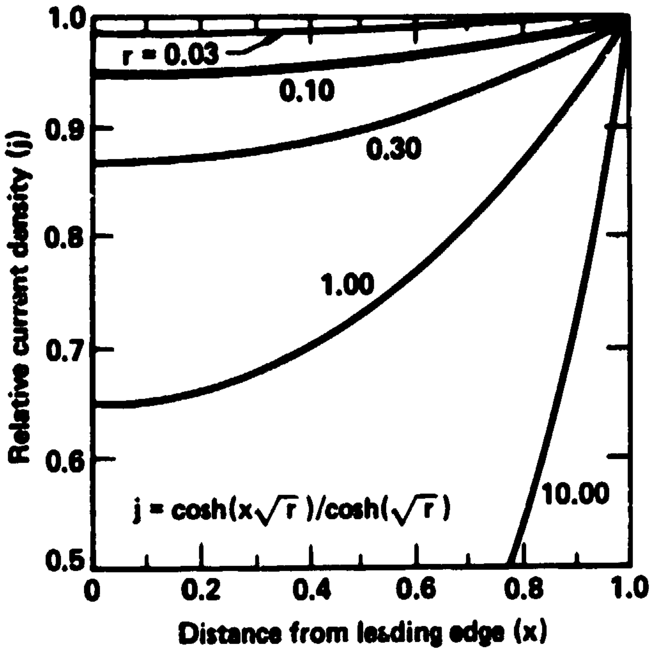

Figure 10. Relative current density increases with the relative distance from the leading edge of the anode. Parameter r is a dimensionless ratio of cell resistivities and geometric ratios given in Table 1.

Table 1 gives the magnitudes of the resistance elements in the M3 cassette. The relative current distribution obtained by the solution of the network problem is given by:

$$j = \cosh(x\ r^{1/2})/\cosh(r^{1/2}), \qquad (3)$$

$$r = \frac{(R_r W + R_c)A_a^2}{(M_o + gR_e + R_a W)}$$

where r is a dimensionless ratio of resistance elements defined in Table 1, j is the current density relative to that at the point where metal enters the cell, and x is the dimensionless distance from the leading edge (apex) of the wedge. A_a is anode length (parallel to ribs), g = interelectrode gap; and W is rib separation. For the M3 cell, r = 0.13, and current density is uniform to within +/- 3%. This nonuniformity imparts a steady-state curvature to the anode which differs from a plane by less than 5 micrometers over the entire surface.

Table 1. Cell Resistance Elements in the M3-Cassette for w = 28 mm, g = 2 mm, and A_a = 0.123 m.

Element	Resistivity	Units	symbol
Cathode screen	1.0 (10^{-3})	ohm	R
Electrode polarization	1.0	ohm-cm^2	m_o
Interelectrode gap	1.770	ohm-cm	R_e
Anode/SSCC rib junction	0.042	ohm-cm	R_a
SSCC rib	7.5 (10^{-5})	ohm/cm	R_r
Characteristic resistance	0.13	--	r

We have developed an advanced Al/air cell based on this geometry (Figure 11) which will provide the program with a reproducible basis, or "reference" for aluminum-air full-cell testing. The cells are machined by computer control, which allows low-cost modifications of dimensions and design according to the intended use of the cells -- eg., research cell, massive reserve battery, low-weight vehicle module. In this cell, electrolyte and air flows are internally manifolded. The module stack at LLNL is plumbed for series electrolyte flow. Smaller cells (25 cm^2 anodes) are also available for program-wide uses.

Wedge cells were originally developed by this program because of full-utilization and partial recharge capability, and simple refueling by addition to plates to a dry chamber above the (undisturbed) cell. The feed slab thickness is independent of cell capacity and can be manufactured by continuous casting operations at an optimum thickness.[9] There are no moving mechanical parts in this design, other than the gravity-fed anode.

4.2 Integration of Prototype Cell, Hydrocyclone and Crystallizer

The hydraulic power consumption of a hydrocyclone can be minimized with the use of an involute entrance chamber. A hydrocyclone of this design (supplied by Krebs Engineers, Menlo Park, CA), was tested with a wedge cell and crystallizer. We confirmed manufacturer's specifications by means of the operation of this cyclone with a single cell. As this unit was large enough for a crystallizer sized for 30-50 of the 600-cm^2 cells, 97% of the overflow was returned to the crystallizer. Measured hydraulic power consumption (product of flow rate and pressure drop) was 35 W. Three would consume about 1% of the 18 kW gross power output of 100 cells (assuming 50% motor/pump power efficiency).

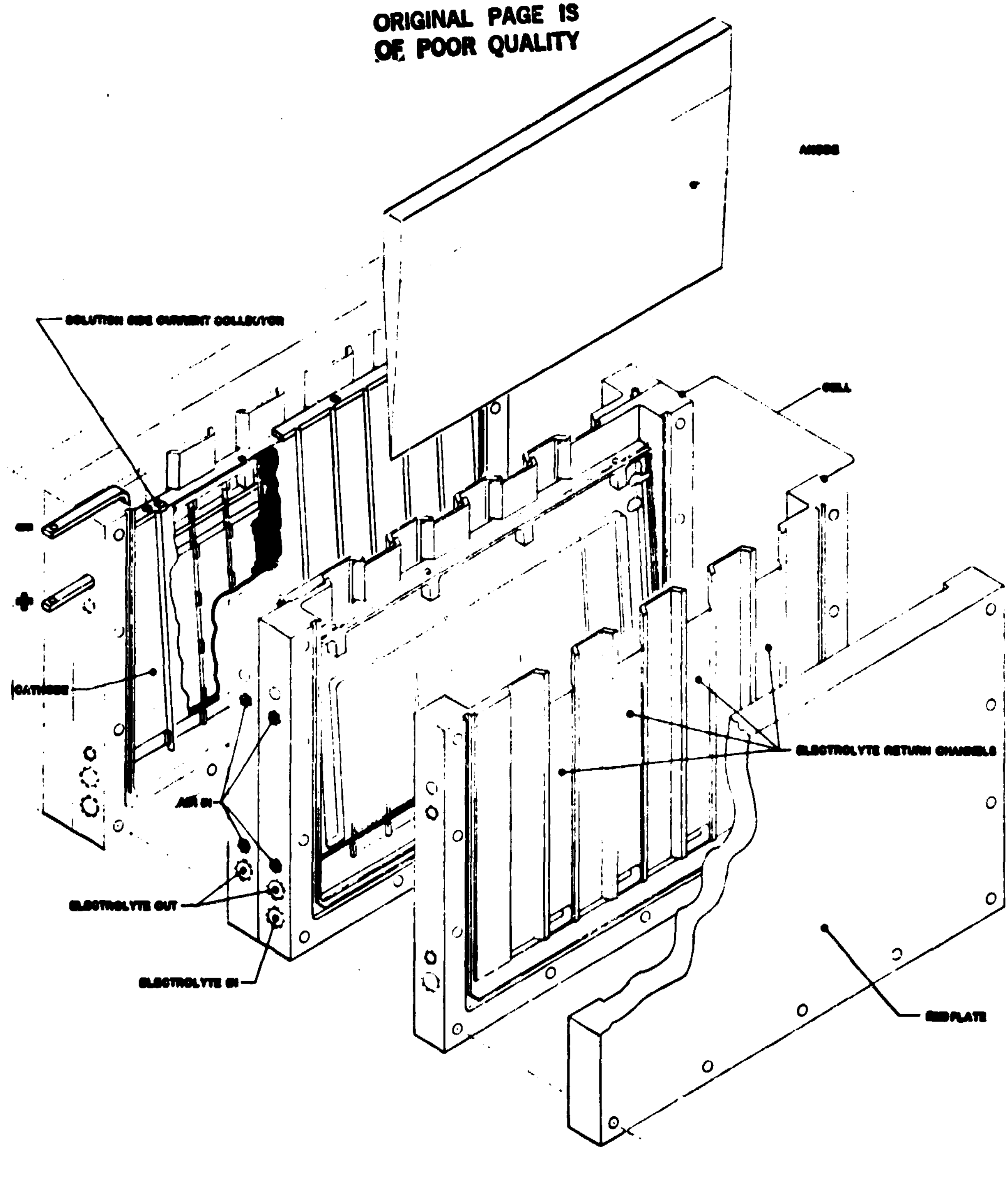

Figure 11. Reference Al/Air cells (advanced generation wedge cells) consist of trapezoidal cassettes with internal manifolding of air and electrolyte flows. Anode area is 600 cm^2, and SSCC design is identical to that of earlier cells.

The rate equation derived by Alcoa describes the kinetics of hydragillite particle growth:[10]

$$-dC_{Al}/dt = K_o \exp(-E/RT)\, A_t\, (C_{Al}-C_{Al}(sat))^2/(C_{Na}-C_{Al})^2$$

where C_{Al}(sat) is the solubility of $Al(OH)_3$, a function of temperature.

Independent particle growth is the predominate mode of precipitation under anticipated battery operating conditions: 40-80°C; well-stirred bed; seed-area/electrolyte-volume ratio, A_t = 10-70 m^2/liter; and C_{Al} less than 2.8 M. Under these conditions, particle nucleation is suppressed. Some particle breakage (attrition) or agglomeration is expected. Precipitation rate in the bed is proportional to the total surface area of the crystals, the square of supersaturation, and the inverse square of a term reflecting caustic activity.[10,11] The term in the denominator explains the sharp increase in the rate above C_{Al} = 2.3 M (Figure 12).

Figure 13 shows time dependence of electrolyte composition when a crystallizer/hydrocyclone system was used to control aluminate concentration. The crystallizer was initially charged with 0.18 kg of seed (specific area, 120 m^2/kg), and $Al(OH)_3$ solids were retained in the crystallizer for the duration of the 6 hour run. The peaking of aluminate concentration in cell and crystallizer after 3 h reflects equal rates of dissolution and precipitation. The current density, 2.3 kA/m^2, is the highest long-duration dissolution rate anticipated for vehicle operation. In this experiment we used unalloyed aluminum; coulombic efficiency exceeded 97% for the duration of the experiment.

Evaluating Alcoa's rate equation at points during the experiment, we determined the rate of precipitation (Figure 14). This rate was then integrated to predict the accumulation of solid $Al(OH)_3$. As shown, this

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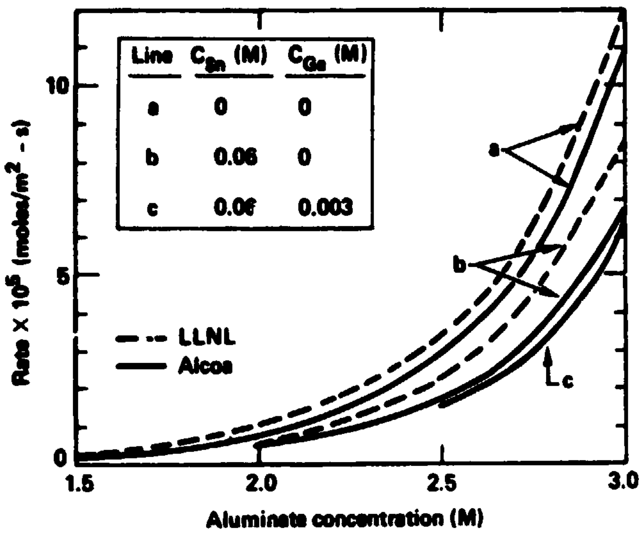

Figure 12. Rate of hydrargillite precipitation increases with temperature and oversaturation, and depends on the nature and concentration of impurities. Rate relations were independantly determined by LLNL[11] and Alcoa[10].

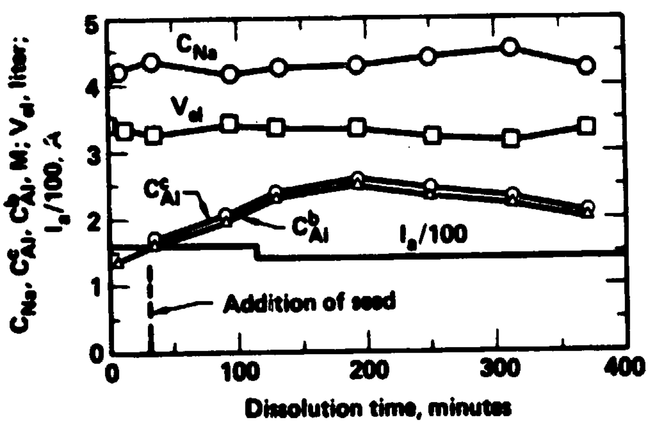

Figure 13. Time dependences of the electrolyte volume and composition, and of dissolution current (I_a) during joint operation of wedge cell and crystallizer/hydrocyclone. Concentration of aluminate is given for the crystallizer as well as the cell circuit.

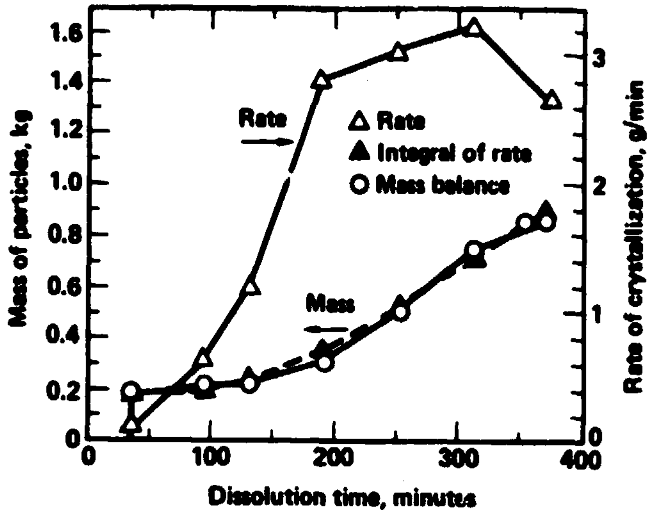

Figure 14. Rate of precipitation, integrated rate of precipitation, and mass of seed (determined from mass-balance calculations) are plotted against dissolution time for the joint operation of wedge cell and crystallizer.

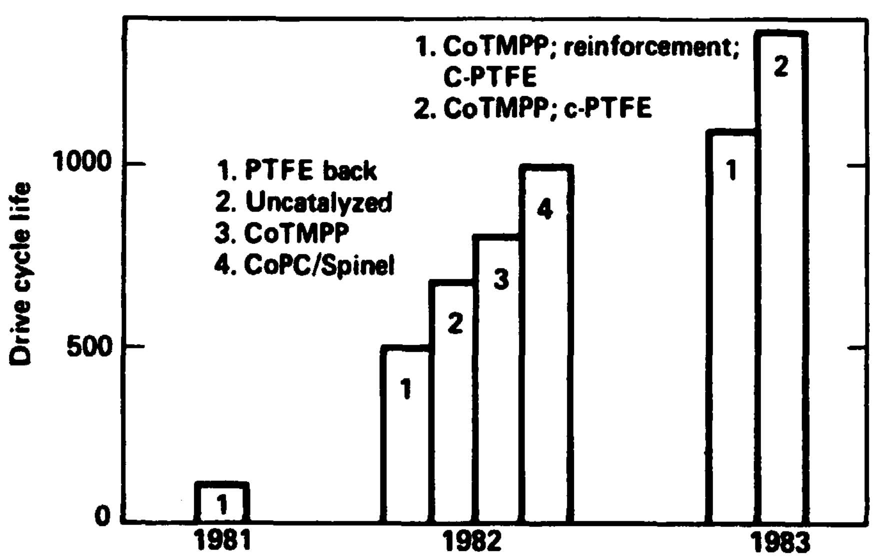

Figure 15. Increases in air-electrode cycle life reflect advances in catalysis as well as electrode carbons, wet-proofing, and sintering processes.

agrees well with the separate experimental mass balance based on Faraday's law, changes in aluminate concentration, and anode weight loss. The salient conclusions are (1) Alcoa rate equation applies to the simultaneous operation of prototype cell and hydrocyclone/crystallizer and (2) this verification was done within the range of critical vehicular operating conditions shown in Table 2. This is the first time that the basic processes of dissolution and crystallization have been integrated using either full-scale prototype components (cell and hydrocyclone).

Table 2. Anticipated operating conditions of a vehicle battery and actual operating conditions of the M3-wedge/hydrocyclone/crystallizer. T = 60°C.

Experimental System	Seed Mass	Seed area/volume	Seed mass/amperage
	kg	m^2/l	g/A
1-Cell System (60°C)	0.18-0.83	8-55	1.3-6
100-cell system[a] (60°C)	25	20-30	2
100-cell vehicle system[a] (optimum 70°C operation)	18	20-30	1.5

[a] C_{Al} = 2.7 M

Current efforts will integrate a five-celled prototype module with an appropriately scaled hydrocyclone separator. The larger scale is convenient for investigation of long term behavior of anode shape, particle size distribution, mass balance of minor components (stannate, or gallium in case of RX808), and behavior of crystallizer during standby when all electrolyte is drained into the crystallizer. This same system will be integrated with auxiliaries for withdrawal and post treatment of mature seed by the prime subcontractor in the first year of the program.

4.3 Progress in Electrode Research and Development

There has been considerable progress in the development of durable and cost-effective air electrodes. Air electrodes are tested on a standard driving cycle consisting of constant current plateaus of 1-, 6, and 2 kA/m^2 and lasting a total of 14 min/cycle; this is followed by a period on standby in cold, supersaturated electrolyte lasting between 1 and 24 h, and typically 3 h. This sequence is representative of a typical automobile trip of 11 km length. By correlating life under such drive cycles with changes in the duration of a specific phase of the cycle, Eltech determined that cycle life depends strongly on the number of cold startups.[12] The original program goal of 1500 cold startups, or two year road life, has now been met (Figure 15). The current generation of air electrodes are projected to survive beyond 2000 cycles. The goal has been reset to 3000 drive cycles, which corresponds to a four-year road life. Table 3 provides air-electrode polarization data for current air electrodes (catalyzed with CoTMPP), program goal, and earlier LLNL specifications in FY 1979 RFP.

Table 3. Current performance, technical goal, and LLNL Specifications for air electrode polarization (initial performance) T = 60°C; 4M NaOH + 1M $Al(OH)_3$.

Current density kA/m^2	Best Obtained CoTMPP V vs. RHE	technical goal V vs. RHE	LLNL specs V vs. RHE
1	807	841	836
2	766	830	796
3	741	823	756
4	706	816	716
5	667	810	676
6	583	805	636

These drive cycles lives were attained with the use of a non-noble metal catalyst (CoTMPP) as necessary to meet programmatic goals of $100/m^2 cathode.

Progress in anode development has been slow because of the greater emphasis on the development of refuelable cells and crystallization processes. Economic feasibility will ultimately depend on energy yield/cost ratio of the alloy. Common scrap aluminum containing iron generally shows low coulombic efficiency associated with the low overpotential for hydrogen evolution on iron inclusions. Under subcontract, Reynolds Aluminum took the approach of segregating iron as Mn-Fe$(Al)_3$ intermetallic clusters with greatly reduced activity from the standpoint of hydrogen evolution.[13] The effect of the introduction of 0.04% Mn to commercial purity aluminum containing 0.04-0.06% Fe is shown in Figure 16. Coulombic efficiency is greatly increased, approaching that of an analogous alloy, RX808, based on 4-9's purity metal. This Al-Ga-Mn-Fe class of alloys was never optimized by the Reynolds subcontract. This and other approaches will be again be pursued in 1984 by Eltech and Ohio State University under subcontract. Although compositions are proprietary, Alcan has produced a number of alloys using the Ca 0.05% commercial purity base with net performance at least as good as this.[14] In all, the program has yet to pursue the scope of research necessary to develope cost-effective anodes; the major effort here will be lead by the prime industrial subcontractor because of the potential value of basic patents in this area.

4.4 Battery Weight Determinations

The battery weight determination given in Table 4 reflects the actual weights of dry laboratory cells, the weights of reactants and hydrargillite seed, and the weights of electrolyte required for battery operation. We have

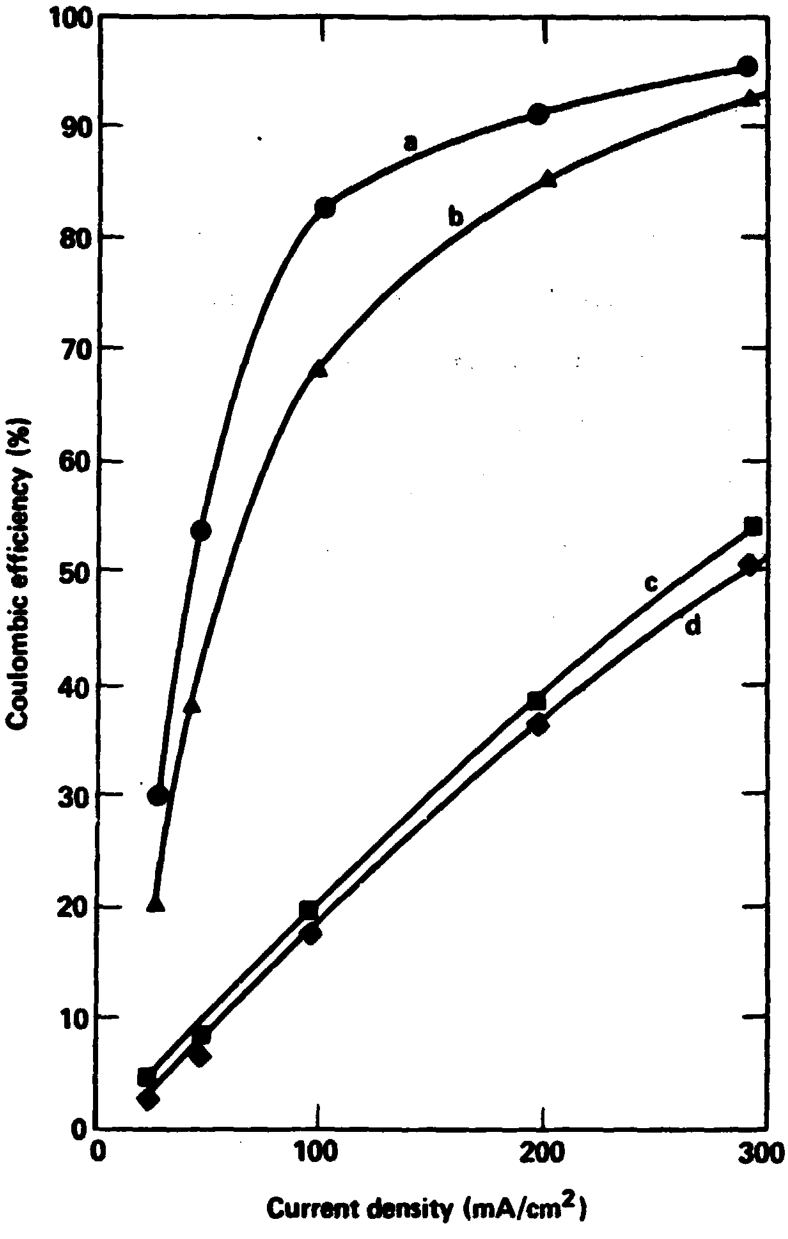

Figure 16. Improvement of coulombic efficiency of RX808 analogues based on commercial purity aluminum is achieved by additions of Mn. The additions form intermetallic clusters which segregate and reduce the activity of Fe from the standpoint of hydrogen evolution. Operating conditions: 60°oC; 4M NaOH + 1M $Al(OH)_3$ + 0.06M $Na_2Sn(OH)_6$. (a) RX808 (Al -0.04Ga -0.8Mg). (b) Al -0.04Ga -0.04Mn -0.8Mg. (c) Al -0.04Ga -0.04Fe -0.8Mg. (d) Al -0.04Ga -0.06Fe -0.8Mg.

assumed a hydrocyclone of cast PVC construction, and surface power density ($W m^2$) and aluminum energy yields which span those of current model electrodes. The optimum weight of the battery and efficiency is achieved if crystallizer and cell operating temperatures are allowed to increase with aluminate concentration such that power density and coulombic efficiency roughly constant. The battery weight resulting from this optimization indicates specific energy of 320 Wh/kg and specific power of about 140 W/kg. Improvements in suface power density anticipated with further alloy developement would increase specific power proportionately. These figures reflect the characteristics of reserve batteries as well as large traction systems, were they to be built consistent with today's understanding. The aluminum-air battery is a fuel cell; hence specific power and energy have no unique meaning. These parameters can be changed by changing the ratio of mass of the limiting reactant (either water of aluminum) to the total area of the cells.

Table 4. Battery Weight Determination: 70 kWh, 31 kW (peak) Scale.

Component	Basis for Determination	Weight (kg)
Cells	M3 wedge cassettes: 1.1 g/cm^2; 5-7 kW/m^2	69-49
Cyclones	Krebs PC-1; PVC construction	2
Electrolyte	Contained in cells, crystallizer,cyclones and manifolding	35[a]
Seed	Alcoa rate equation; C_{Sn} = 0.06 M	18[a]
Aluminum	Fuel requirement, 4-5 kWh/kg	17.5-14
Wedge	3° angle geometry	26
Water	Reaction and evaporation loses	32
Storage	Water, electrolyte, hydrargillite storage tanks	3
Misc.	Cell case, impellers, air-pretreatment, drive motor, startup battery etc. (estimate)	30
	Total:	209-233

[a] Temperature = 70° at maximum C_{Al} = 2.7 M; seed area/mass ratio = 66.1 m^2/kg; seed area/electrolyte volume ratio = 30 m^2/liter.

5.0 Major Problem Areas and Technical Approach

Vehicle operating cost depends predominately on the energy yield and production cost of the fuel alloys. An increase in energy/cost ratio of 30% over that of the Reynolds Al-Mn-Ga is required before our goal of 8.5-10¢/mile is to be realized. The approaches to be taken include (1) reduction of dissolution overpotential through alloying with such materials as Ga at 0.02-0.04% levels; (2) selective poisoning of the hydrogen evolution reaction by use of alloyed or dissolved corrosion inhibitors (e.g. Sn, P) or intermetallic formation to segregate Fe or other undesirable impurities;

(3) use of a porous surface barrier formed by the reaction of an alloyed component (eg, Mg) to form a high-concentration layer with higher coulombic efficiency; (4) use of trace metals to expand or contract the metal sublattice of the surface film which effects the balance of electronic and ionic conduction, and hence relative rates of water reduction and aluminum dissolution. Fundamental anode research will be emphasized as battery development approaches full-scale verification. No definitive projection of fuel cost can be made until this area is understood.

A potentially important area is the chemical balance of the battery, i.e., problems in battery efficiency and operating stability that could conceivably arise from the inadvertent buildup of trace impurities in the electrolyte and on the electodes, or from the depletion of corrosion inhibitors. The control of impurities will be investigated by Alcan, Ltd.

It is important to determine or predict purity constraints of current and projected aluminum production techniques. In addition to alloys based on the limiting commercial purity of conventional Hall smelter operation (0.04-0.06% Fe), higher purity bases may be obtained through partial recrystallization from the combined outputs of large arrays of undedicated cells. Advanced processes such as the Alcoa Smelting Process, subhalide processes, sulfide or nitride electrolysis, or dimensionally-stable anode processes do not have the purity limits of the conventional Hall Process. The Mitsui Carbothemic Reduction Process involves the sublimation of Al from an Al/Pb intermediate product; the purity of the aluminum exceeds that of the common Hall Smelters yet the process consumes no net electricity.[15] Thus research in alloy development must take into consideration parallel advances likely to occur within the appropriate time frame for vehicle fleet introduction and growth.

Another barrier is cathode reliability (as distinct from drive cycle life). Insufficient experiments have been conducted to allow a statistical understanding of the failure rate. This problem is less severe than with fuel cells because of the ability to sense incipient failure from electrode potential decay and to replace individual cathode cassettes.

None of these problems, if given appropriate attention, is expected to deter the different but straightforward development and testing of a vehicular prototype battery--a major and necessary step toward the realization of this concept. Required development separating the current level of technology from that of the prototype vehicle battery is difficult but reasonably straight-forward. The prospects for developing cost-effective alloys are still unknown, but the range of variables known to effect electrode efficiency is cause for optimism.

6.0 Cost and Energy Consumption

The alloys (RX808 and analogues) used as a model anode for cell testing and process development are not economically suitable for a consumer vehicle, as they are based on metal purities (99.99+% Al) greater than those achievable with conventional Hall smelter practice. McMinn and Bransdscomb of Reynolds[9] determined the cost of the Al-0.04Mn-0.04Fe-0.04Ga alloy mentioned above, as part of an effort to bracket the production cost of fuel plates.[13] The composition of a cost-effective alloy will no doubt differ; the unit costs of fabrication and alloying will probably not differ appreciably from those shown in Table 5. To estimate fuel cost, the cost of alloying agents is added to the U.S. Industry published price (which includes delivery charges to any point in Continental U.S.). This in turn is increased by the costs of continuous casting and shearing operations; and retail markups to equalize profitability of aluminum and ICE refueling. Credit for recycled $Al(OH)_3$ is derived from producers' price less 15% profit, collection and handling,

freight and calcining costs. The fuel cost requires assumptions concerning energy yield. Time-averaged energy yields of 4.3-5.9 kWh/kg-Al correspond to roughly 36-42 tonne-km/kg vehicular efficiencies, which in turn indicate fuel costs of 8-10 ¢/mile. (See Ref. 4 for details of these relations.)

Table 5. Estimates of the Cost of Fuel Plates with Reference to Al-0.04Ga-0.04Fe-0.04Mn.[1,4]

Cost Factor	Basis for Estimate	Cost ($/kg)
Base price	U.S. Industry published price (ingot delivered to point in continental U.S. (1981 $)[a]	1.670
Fabrication	Continuous casting and shearing to rectangular slabs	0.154
Alloying agents	Ga and Mn	0.053
Premium purity	5A base containing 0.04% Fe	0.077
Retail markup	Profit equivalent to that of gasoline used in comparable vehicle	0.070
Recycle credit	Producer's price less 15% profit, collection, transport, and calcining charges	-0.306
Total:		$1.72/kg

[a]This is also the current price as of January, 1984.

Electrical energy uses for current and advanced process for aluminum production are shown in Table 6. Since our earliest studies of energy cost of aluminum production, several process advancements or new processes have emerged and been demonstrated in pilot plant operation. A new plant built in

the 1990's time frame will likely reflect these or comparable advances.

The significance of energy use calculations is rather questionable. Ideally, we make such calculations in an effort to estimate the impact of the introduction of a fleet of vehicles on national energy consumption. The introduction of one million aluminum-air vehicles in the 1990's may cause an increase in the nation's consumption of energy or a decrease; or no measurable change at all. The change of energy use depends on how the production market responds to small perturbation on demand--i.e., whether the demand is met by new (efficient) plant construction increase of production at existing (less efficient) plants. Electrical energy use would go down if aluminum (as fuel) merely displaces other uses of aluminum where cheaper alternatives are available (for example, containers and packaging). The net change in primary energy use will reflect the net changes in electrical energy use and petroleum (or synfuel) savings. The fact of the matter is simply: there is no way to predict the short-term effect on energy use caused by a small fleet of aluminum-air vehicles.

In the very long run (year 2000 and beyond) new production plants will have to be built to accommodate a growing fleet of aluminum-air vehicles, and the energy use of new processes will enter the determination. We are in no position today to speculate which process (or processes) or how much electricity (if any) is used by the new plants constructed in so remote a time frame. The evolution of the aluminum industry is a currently ongoing process and is driven by the same basic energy considerations that mandate the development of alternative fuels for transportation. Thus the process of Table 6, which represents current industrial (Pechiney) or pilot processes are conservative estimates for the year 2000 and beyond.

Table 6. Electrical Energy Use of Current and Advanced Processes for Aluminum Production. (For comparison, unalloyed aluminum yields a maximum of 4.5 kWh/kg in test cells).

Process	Basis	DC Electrical Energy Use
Pechiney, St. Lucienne	Advanced Hall process[16]	11.3 kWh/kg
Alcoa Smelting Process	Electrolysis of $AlCl_3$[17]	8.3 kWh/kg

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APPENDIX J

METHOD OF ANALYSIS

METHOD OF ANALYSIS

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METHOD OF ANALYSIS

This appendix describes the method of analysis used to assess Battery Developer Estimates for the projected selling price of advanced batteries. The method yields a revised subjective estimate which is identified as an Investigator Estimate. The method has been developed in a series of battery cost analysis projects performed by the author beginning in 1978 (Ref. Resource List).

From this experience, the following general observations can be made. The margin of uncertainty or potential error in any early new product cost estimates is strongly related to the level of knowledge, and the related experience the developer has for both product design and manufacture at the time the estimate is generated. The higher the level of knowledge and related experience the lower is the likely margin of uncertainty or potential error in the estimate.

- In my judgement, early product cost estimates are more likely to underestimate rather than to overestimate the realized product cost.

The analysis procedures provide a framework for systematically examining the available information. The major thrust of the analysis is to identify qualitative and quantitative factors which permit an assessment of the developer's level of knowledge and related experience at the time the estimate was generated.

On the basis of this assessment subjective quantitative adjustments are made to the three key parameters--material and component costs, direct labor hours, and installed equipment costs--to obtain the Investigator Estimate.

The major segments of the method of analysis are outlined in Table J-1. A brief elaboration is given for each segment with illustrations of some for the factors examined in each segment.

BATTERY TECHNOLOGY

The primary interest is to identify materials or components not fully developed or commercially available which if current goals are not achieved could significantly impact on the cost estimate. Examples of the these factors are porous graphite cost projections for the zinc-chloride battery and electrolyte tube material purity and cost projections for the sodium-sulfur battery.

MANUFACTURING TECHNOLOGY

The primary interest is to examine the process flow sheet definition and the extent of process development and equipment development needs. Examples of these factors are the need to demonstrate that large scale graphite production costs will meet projected costs used in the estimates for zinc-chloride battery. Another example is the ability to achieve projected yields of electrolyte tubes for the sodium-sulfur battery.

KEY PARAMETERS

The primary interest is to establish on a quantitative basis the reasonableness of the values generated by the developer for material and component costs, direct labor hours, and installed equipment costs.

Material and Component Costs

The factors of interest in this category are the development status of dominant cost items, consistency in estimates made at different times, recent progress in performance and design improvements, the level at which these improvements have been demonstrated i.e. single cell versus full scale hardware at current level of demonstration, and finally the basis for and documentation of process yields and unit costs assumed.

Direct Labor Hours and Equipment Costs

The direct labor hours and equipment costs must be examined together since for a given product design and manufacturing process they are interrelated. The exact relationship depends on the type of processes and equipment employed; and the trade-offs made between decreasing labor content and the increased costs of automation or scaling of equipment as a function of production rate.

The principal considerations in the analysis for this segment are:

- The development status and definition of the manufacturing process and equipment needs.
- The basis and documentation of the direct labor and equipment estimates.
- The consistency of the estimates referenced to a lead-acid battery manufacturing parameter correlation.

The choice of the lead-acid battery as reference for measuring the consistency of the developer estimates is based on several factors. Lead-acid battery manufacture is based on a mature technology, and reflects the benefits of optimized and automated process and plants. The data base for the lead-acid battery system is more accurate than the data base generated for batteries still under development.

The consistency of the developer estimates for direct labor hours and manufacturing equipment costs is based on examining how these values correlate with corresponding lead-acid values. The correlating parameter utilized is the ratio of the total number of manufacturing operations required for the battery under consideration to the total number of manufacturing operations for the lead-acid battery. Interpretation of this correlation requires a comparison of three other parameters for the battery under consideration and the lead-acid battery. These parameters are the scaling

factors for the operations, the number of components processed per unit of product, and the capacity of the manufacturing plant. From this analysis it is possible to obtain a subjective quantitative estimate of the consistency of the developer's estimates. A more detailed description and derivation of this analysis is given in the Appendix K.

DEVELOPER DISCUSSIONS

Issues and questions raised in the above segments are discussed with the developer for clarification. It is my experience that these discussions do not yield uniform clarification. The major barrier is the developer's position or perception that the issues impinge upon information that is considered company proprietary. It should be noted that the extent to which this method of analysis can be implemented depends significantly on the amount of information the developer wishes to share. The greater the cooperation between the developer and investigator, the less important is the subjective element in the Investigator Estimate.

DEVELOPER CAPABILITY ASSESSMENT

From the analysis results of the first four segments described above, an assessment is made of the developer's overall capability at the time the developer generated the estimates under evaluation. This assessment considers three factors:

- Level of knowledge with respect to product design and product manufacture.
- Extent of related experience with respect to product design and product experience.
- Depth, detail and the extent of documentation pressented in the design and cost estimate study supporting the estimates made by the developer.

An additional subjective estimate is made as to whether the overall approach of the estimate is conservative or optimistic.

This assessment is one factor utilized in making the determination of the Investigator Estimate.

INVESTIGATOR ESTIMATE

On the basis of the results of the Key Parameter Analysis, Developer Discussions, and Developer Overall Capability Assessment subjective adjustments are made to the Key Parameters to determine the Investigator Estimate.

Table J-1. Outline for Determining Investigator Estimate

(1) Status of Battery Technology, especially in relation to battery design, materials and components and performance specification assumed in the design for the cost estimate.

(2) Status of Manufacturing Technology, especially with regard to the definition or demonstration of process flowsheet, process and equipment development needs for manufacturing the battery design assumed for cost estimate.

(3) Analysis of developer's estimates for the three key parameters--materials and component costs, direct labor hours, and installed equipment costs for the production rate specified.

(4) Discussion with developer to clarify issues raised in the above analyses.

(5) Evaluation of developer's "overall capability" at the time of generating his developer selling price estimate.

(6) Determine Investigator's Estimate by making subjective adjustments to item (3) parameters in conjunction with evaluations made in items (3), (4) and (5).

RESOURCE LIST

Method of Analysis

(1) Cost Analyses - Nickel-Iron and Nickel-Zinc Batteries; and Lead-Acid Batteries (1978)
J.A. Consiglio, Solva-Tek Associates
Argonne National Laboratory Purch. Order No. 955230

(2) Advanced Batteries Cost Analyses For Electric Vehicle Applications (1980)
J.A. Consiglio , Solva-Tek Associates
Dept. of Energy Contract No. DE-AC02-ET25418

(3) An Assessment of Westinghouse Ni-Fe Battery Cost Parameters (1981)
J.A. Consiglio, Solva-Tek Associates
Westinghouse Electric Corp. Purch. Order No. 54-7WAE 318866

(4) Evaluation of Developmental Battery Cost Estimates (1983-84)
P.C. Symons, Electrochemical Engineering Consultants, Inc.
J.A. Consiglio, Solva-Tek Associates
Electric Power Research Institute
Agreement RP-1136-24,25

APPENDIX K

DIRECT LABOR AND EQUIPMENT COST CORRELATIONS

DIRECT LABOR AND EQUIPMENT COST CORRELATIONS

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This appendix describes the method utilized to assess the magnitude of the direct labor and installed equipment cost estimates prepared by the developers. This assessment is then utilized to make subjective adjustments to these two parameters to generate the Investigator Estimate. (Reference Method of Analysis Text.)

The assessment is based on the use of corresponding information (direct labor and equipment cost estimates) for the lead-acid battery as a reference point. The following discussion includes three topics:

- Relation of direct labor and equipment costs to parameters
- Correlation of direct labor and equipment costs
- Correlation results

DIRECT LABOR AND EQUIPMENT COST PARAMETERS

A manufacturing process for the production of a battery can be represented by a number of process operations by which materials and components are fabricated and assembled into the battery. A given material or component may require a number of different operations prior to being assembled into the battery. Thus, for a specific battery design with a known number of components, a total manufacturing process can be specified with process operations of the appropriate type and capacity to produce the battery at a specified rate.

These concepts are illustrated for a single manufacturing operation and a single component in Figure K-1. Note that the illustration is for Direct Labor, but the arguments and relationships to the parameters also apply to Equipment Costs.

For this process operation, there is associated a direct labor content per component expressed as DL_C in hours per component. DL_C can be expressed as a function of three parameters: the capacity of the process operation (components per unit time); and a scaling factor and a complexity factor which characterize the type of operation. This relation is expressed symbolically in the first equation. The term $F_C(SF*CF)$ signifies a function F_C of the two parameters scaling factor (SF) and complexity factor (CF).

The scaling factor (SF) is expressed as an exponent. For example, in the case of a punch press having a specified capacity, if there is a need to double the production rate, then two punch presses would be required. The corresponding amount of labor and or equipment requirement is doubled. For this type of operation the scaling factor exponent has a value of 1.0.

Another type of operation is illustrated by a chemical reactor in which the volume of the reactor is the critical parameter. The capacity of the reactor can be doubled by doubling the volume of the reactor. The scaling factor exponent for this type of operation, based on experience, is generally less than 1.0--varying from 0.6 to .8. In this case, labor and/or equipment costs would range from 1.52 - 1.74 instead of doubling as in the first case.

The complexity factor (CF) reflects the fact that a more complex process operation will have associated with it a higher intrinsic labor requirement and/or equipment cost. Examples of this situation are a machining operation on a lathe operating to a variable slope pattern and high tolerances versus the stamping out of metal pieces in a punch press. The former will have higher intrinsic labor content and higher equipment cost than the latter.

The second equation in Figure K-1 expresses the labor requirement on a per unit product basis. This is obtained by multiplying the DL_C value of the first equation by the number of components required per unit product. The last equation represents symbolically the total labor required to produce a product by summing up all component and associated operations in the manufacturing process to produce the product.

The estimates from the developer in most cases were not presented with the detailed information for the parameters just described. The most common set of information included a process flowsheet indicating the number and types of operation. From this information a subjective judgement could be made as to the scaling factor being 1.0 or less than 1.0. The production capacity of the battery manufacturing facility was also specified. From the battery design specification the total number of components per product unit could usually be determined.

Thus, the common set of available information permits an assessment based on:

- The number of total manufacturing operations
- The fraction of total operations having scaling factors of 1.0 or conversely less than 1.0
- The total number of components per product unit
- The capacity of the manufacturing facility

The method whereby this information is correlated to the corresponding lead-acid battery data is presented in the next sub-section.

DIRECT LABOR AND EQUIPMENT COST CORRELATION

The following discussion is facilitated by defining a number of terms which will be used in abbreviated form as follows:

DL direct labor estimate in hours per KWH of battery rated capacity

EQ equipment cost estimate (installed basis) in $/KWH of annual manufacturing capacity

EXP the exponent of a straight line on a log-log plot, which is the value for the slope of the line.

Manufacturing Operation Ratio The ratio of the number of manufacturing process operations for the production of a given battery to the number of manufacturing process operations for the production of the reference lead-acid battery. These are obtained from an analysis of a manufacturing process flow sheet.

The primary comparison is made by examining the relationship of DL and EQ for a given battery versus the Manufacturing Operations Ratio. The values of DL and EQ for the lead-acid battery are used as reference point origins for drawing tie lines between the origin and the given battery data points. One plot is made for DL comparisons and one for EQ comparisons.

The data are plotted as log-log type plots. This type of plot is illustrated in Figure K-2 for the Ni-Fe and Na-S batteries with selected non-proprietary data generated in earlier studies.

The dotted line extension from the origin point with an exponent of 1.0 represents an Imaginary lead-acid plant with additional number of operations. The mix in types of

the additional operations in terms of scaling factor exponents, and DL to EQ ratio are the same as the original reference lead-acid battery plant. The plant capacity for the Imaginary plant adds no additional capacity. The capacity of the original lead-acid plant combined with the Imaginary plant equals the original lead-acid battery capacity.

The question addressed in the comparsion - are the positions, or slopes, or exponents for the DL and EQ lines, in each plot, consistent with reference to the Imaginary lead-acid plant line of slope 1.0?

Three parameters in Table K-1 impact on the value of the exponents of the tie lines to differing degrees and in different directions. The parameters are:

- Plant capacity or production rate
- Number of components per KWH of battery rating (in this illustration limited to components through the cell level or equivalent thereof).
- Percentage of manufacturing operations judged to have a scaling factor exponent of approximately 1.0 with respect to production rate.

The procedure used is to make a comparison of the parameter values for the given battery versus the lead-acid battery values for the same parameter - Table K-1. From this comparison a judgement is made as to the expected impact of the parameter on the position of DL or EQ tie line with respect to the Imaginary lead acid plant tie line with an exponent of 1.0.

The complexity factor (CF) also impacts on the value of the exponents of the tie line. This information was not quantifiable in this analysis. A qualitative subjective assessment of this factor was utilized as a guide in making the judgement of the expected impact of the three parameters listed above.

The process is illustrated for one parameter - Plant Capacity for Ni-Fe. Nickel-Iron plant capacity is much less than the capacity of reference plant (21 MWH versus 2500 MWH per year). At lower production rates DL and EQ increase markedly, therefore the expectation is that for this parameter, Ni-Fe DL and EQ tie lines will be much greater than 1.0.

This process is repeated for each parameter for each battery. The results are summarized in Table K-2. All entries are expectations against the reference exponent value of 1.0.

In summary the expectation is that the exponents for Ni-Fe DL and EQ lines are much greater than 1.0 and for Na-S the exponents are about equal to 1.0. A comparison with Figure K-2 indicates that the results for Ni-Fe and Na-S meet the expectations.

For cases in which the developer DL or EQ values do not meet the expected values as obtained by comparisons drawn in Table K-2 a qualitative assessment is made to determine if there are significant differences between the complexity factor for the developer's process operations and the reference lead-acid process operations. A subjective adjustment is made to the developer's DL and EQ values taking into consideration the above assessment.

PARAMETERS

DIRECT LABOR (DL_C)
- HOURS/COMPONENT

A M'F'G
PROCESS
OPERATION

CAPACITY (CAP) -COMPONENTS/TIME
SCALING FACTOR -SF
COMPLEXITY FACTOR - CF
NUMBER OF COMPONENTS -NO. COMP.

Basis per component $DL_C = \frac{F_c \text{ (SF*CF)}}{\text{CAP}}$

Basis per product DL = NO.COMP. x DL_C

Basis per Total M'f'g Process DL = SUM OF TOTAL NO. OF OPERATIONS

Figure K-1. Direct Labor Correlation Parameters

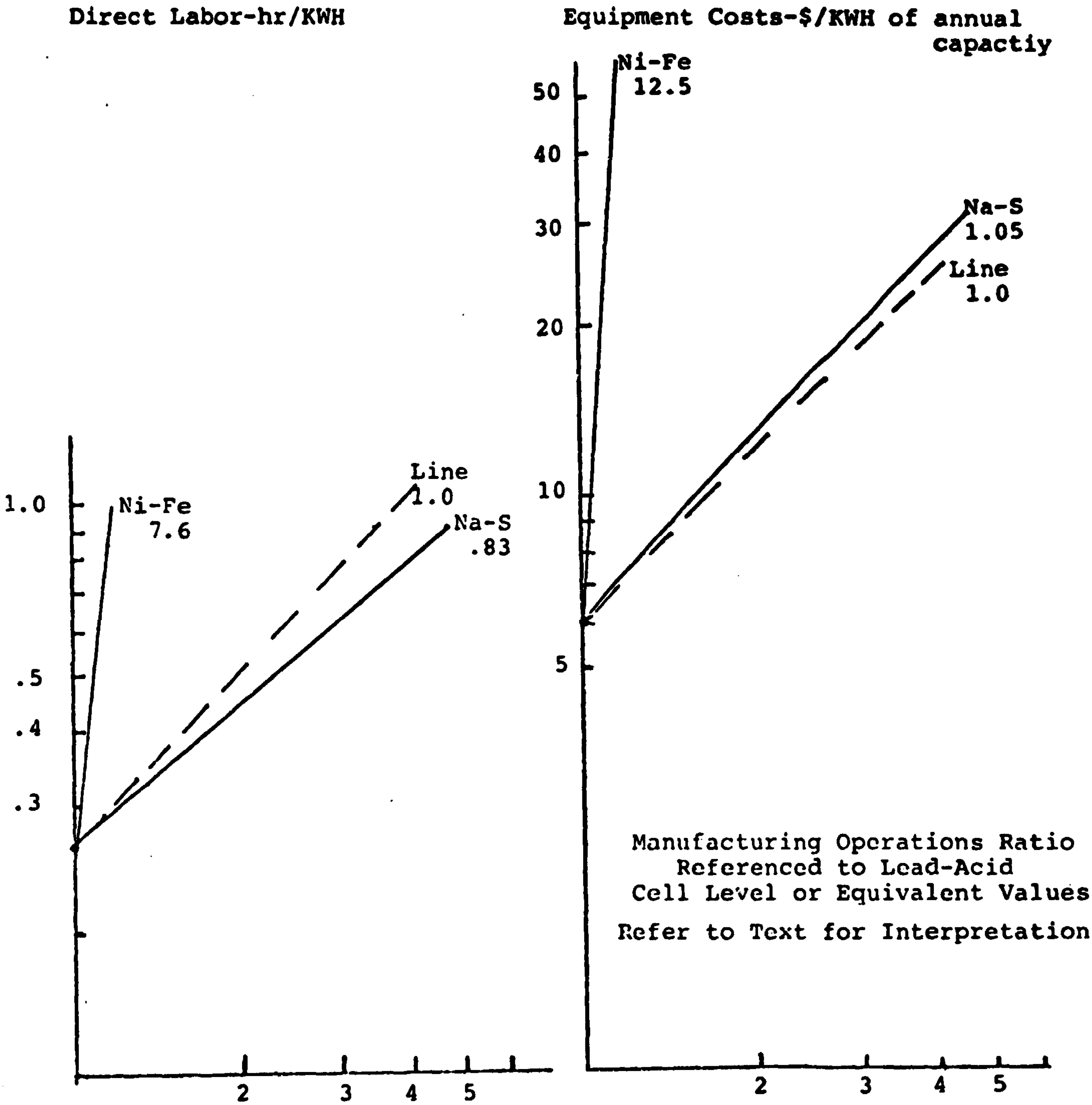

Figure K-2. Direct Labor and Equipment Costs vs Manufacturing Operations Ratio

Table K-1. Selected Parameters for Direct Labor and Equipment Comparisons[a]

	Pb/Acid Ref.	Ni/FE EPI	Na/S FORD
Components-No.KWH	218	230	70
M'f'g Operations-No.	29	34	139
M'f'g Operations Ratio[b]	1	1.2	4.7
Percentage of Operations with Scaling Factor Exponent = 1.0	66	38	74
M'f'g Production Capacity--MWH/y	2500	21	3000
Direct Labor--hr/KWH	.25	.99	.9
Equipment Inv.--$/KWH of annual m'f'g capacity	6.0	58	31

[a]Values for Cell Level.
[b]See text for definition.

Table K-2. Expected Impact of Parameters on Direct Labor and Equipment Cost Tie Lines in Figure K-2

Parameter	Expectation Referenced to Exponent Line Value of 1.0	
	Ni/Fe Eagle Picher	Na/S FORD
Production Rate	Much Greater	Equal
No. Components Per KWH	Equal	Less
% of M'f'g Operations with Scaling Factor Exponent of 1.0	Somewhat Less	Somewhat Greater
Summary Expectation	Much Greater	About Equal

APPENDIX L

WEIGHT AND COST COMPARISON OF ALUMINUM AND STEEL VEHICLE BODIES

Weight and Cost Comparison of
Aluminum and Steel Vehicle Bodies

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I. INTRODUCTION

Efforts by transportation system designers and manufacturers to produce more efficient and higher performance vehicles have led to weight reduction through downsizing and material substitution. The most efficient approach to weight reduction is accomplished by a combination of vehicle redesign in conjunction with material substitution. This allows for the most efficient use of the selected materials.

The purpose of this study is to analyze the impact on the different aspects of manufacturing and to determine a weight and cost comparison of an aluminum body to that of a steel body. For this study it was assumed that the vehicle was redesigned to obtain the optimal use of aluminum while incorporating the necessary changes to effect proper aluminum processing in fabrication and assembly. It was also assumed that the production methods utilized would produce 300,000 units per year.

Supportive materials published over the past six years were reviewed along with discussions with automotive manufacturers and manufacturing development personnel to determine the present status and development of aluminum in automobiles

along with any advantages or disadvantages encountered. The writer also relied on his experience with substitution of aluminum in the fabrication and assembly processes at the GM Lordstown facility. During this time the Vega 15 style substituted aluminum for steel on the load floor cover and a production tryout of aluminum deck lids was conducted on the 11 style.

The published materials were well documented in the material costs and forming of component panels. In most studies when no weight savings was accomplished the component item was then left as steel. This would not be practical in a unitized body due to galvanic reaction, therefore, components would require to be made of aluminum even though a weight reduction were not realized and a resultant cost penalty would be encountered.

The technology exists to design and manufacture vehicles with an all aluminum construction. Existing aluminum alloys have the capability to be formed and welded with existing mass production techniques. In reviewing the materials it was noted that cost penalties were found in all facets of manufacturing that would increase the purchase price of the vehicle. The

trade off of economy and performance to the increased purchase price must be analyzed to determine if the material substitution is economically desirable.

This report is divided into four sections as follows:

II Summary

III Material Weight and Cost Comparison

IV Impact on Fabrication Operations

V Impact on Assembly Operations

An area not covered would be the impact on after market and repair procedures. Increased skills and improved equipment will be required in welding and repair of the aluminum primary and secondary structural components. This would result in higher repair costs and possibly insurance premium increases.

II CONCLUSIONS

Constuction of an all aluminum body can be accomplished with existing mass production methods and obtain a weight savings of approximately 41% in the body structure. This, when related to the total automobile, including the propogated weight savings would be approximately 21% of a base 820Kg vehicle.

The cost impacts were found in all areas of manufacturing. This included higher base material cost icreased tooling, facilities, and manpower. All areas considered, it is estimated that the body would cost 240% more than the steel body.

III. MATERIAL WEIGHT AND COST COMPARISON

As a basis for this comparison the vehicle used in SAE papers 810228[1] and 810229[2] was used. This was a 1981 front wheel drive, four passenger compact vehicle. The components evaluated for alternate material were the body-in- white primary structural and secondary structural components. These components made up the major portion of the body structure with a total mass of 315 Kg. This breakdown is shown pictorally in figure 1.

The major consideration in determining material substitution is to insure that the resultant component has adequate stiffness and strength. The material thickness must also be sufficient to withstand the manufacturing processes such as forming, surface finishing and handling. Exposed components must have sufficient resistance to denting.

The costs for steel and aluminum used were the same as the GM reports. Aluminum costing \$1.70/Kg and steel at \$0.40/Kg. Only one cost for aluminum at a median price was used rather than the different prices for exposed and unexposed finish materials. Also no price difference was established for blank size and offal. Such an analysis would be time consuming and require full design and processing information. A penalty of 15% was assumed in the price impact to compensate for the larger blank requirement and increased material cost.

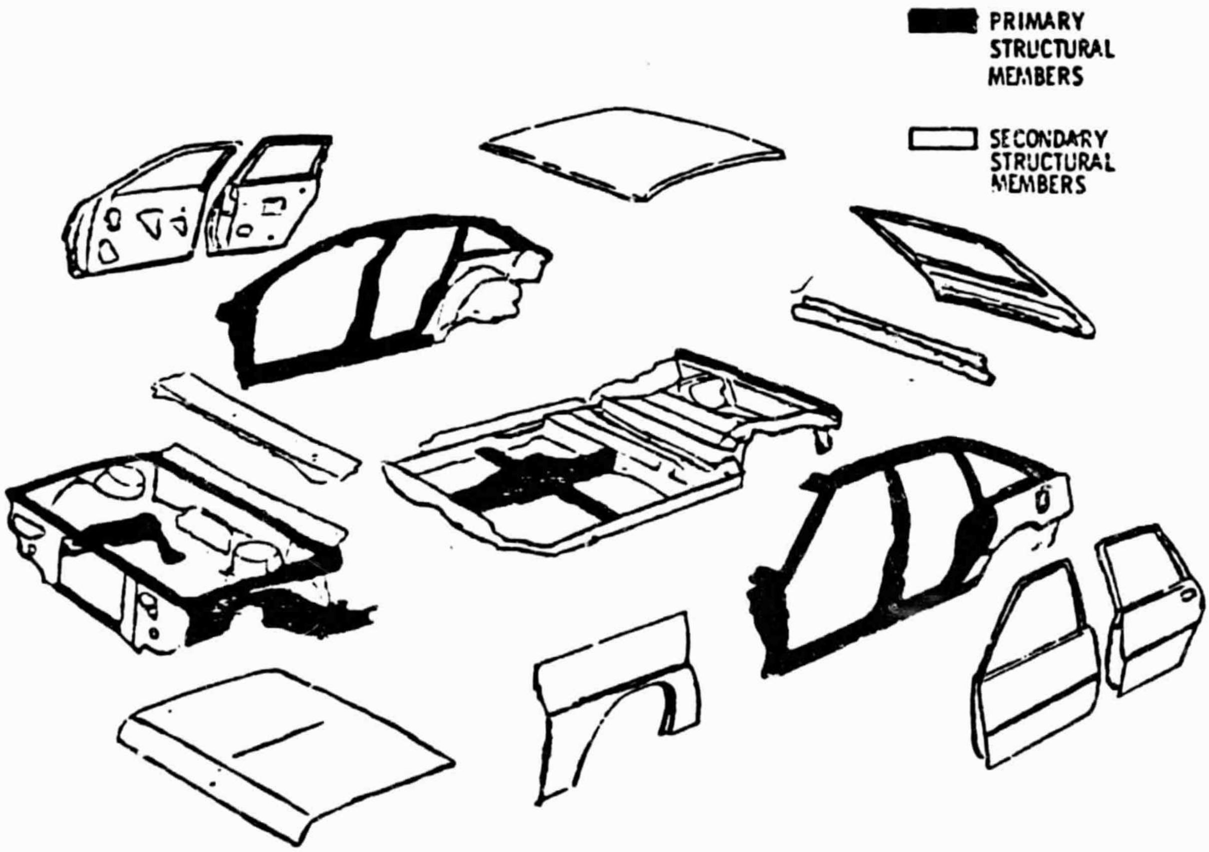

Figure 1- Pictoral Breakdown of Automotive Body

The primary structural members function as the main load carrying structures. These consist of upper and lower front frames, all pillars, rockers, roof rails, headers, floor tunnel, etc. The secondary structural members do not contribute significantly to the structural stiffness requirements. The design criteria of the secondary structural members are generally governed by localized requirements. These consist of the roof panel, doors, floor pan, hood, deck lid, etc.

The total mass of the vehicle as developed in the GM reports are shown in Table 1. The primary structure was developed in aluminum and optimized utilizing the computerized program ODYSSEY, developed by GM. This program, through material substitution and optimization of component design, established an all aluminum primary structure mass of 71Kg or a savings of 34Kg. The secondary structural components were developed as shown in Table 2. A secondary structural mass of 122.5Kg was established or a savings of 52.25Kg.

Approximately 54Kg of the body weight is in brackets, braces, reinforcements and attaching parts that would not benefit from the primary reduction of material substitution. However, some weight reduction would be obtained by the propagated weight savings. This is the weight savings that can be obtained in the chassis, engine, brakes, etc. as a result of the base weight

reduction. Each manufacturer and the different research firms have developed different methods of calculating the propagated weight savings. For this report a factor of 1:1 was used. This means that for every 1Kg of weight saved by material substitution a secondary savings of 1Kg would be obtained. As this is a unitized body it was assumed that half of this amount was to be realized in the auto body and the other half in the drive and suspension. This relates to an additional 43Kg savings in the body or a total of 86Kg for the total vehicle.

As shown in Table 1 this would be an increased material cost of $237.15 or a 289% increase. This related to the finished component and assembly purchase price would be a 30% increase of the final product.

MATERIAL WEIGHT AND COST COMPARISON

Vehicle Area	Steel Weight	Steel Cost	Aluminum Weight	Aluminum Cost	Weight Savings Kg	Cost Penalty $
Primary Structure	105 Kg	$42.00	71 Kg	$120.70	34 Kg	$ 78.70
Secondary Structure	175 Kg	$70.00	122.75Kg	$208.68	52.25Kg	$138.68
Miscellaneous	35 Kg	$14.00	35Kg	$ 59.50	---	$45.50
	315 Kg	$126.00	228.75Kg	$388.88	86.25Kg	$262.88
	Secondary Savings		-43 Kg	-73.10	+43 Kg	-73.10
			185.75Kg	$315.78	129.25Kg	$189.78
	Offal penalty 15%			$ 47.37		$ 47.37
				$363.15		$237.25

Table 1

MATERIAL WEIGHT/COST COMPARISON FOR MAJOR SECONDARY STRUCTURAL COMPONENTS

CRS vs ALUMINUM

DESCRIPTION	QTY	STEEL[1] Mass	STEEL[1] Cost	ALUMINUM Mass	ALUMINUM Cost	Weight Savings Per Vehicle	Cost Penalty Per Vehicle
Compt Pan Frt	1	6.75Kg	$2.70	3.58Kg	$6.09	3.17Kg	$ 3.39
Compt Par Rr	1	7.16	2.86	3.79	6.44	3.37	3.58
Mtr Compt Frt	1	3.03	1.21	1.48	2.52	1.55	1.31
Dash Ext Upr	1	1.98	0.79	0.97	1.65	1.01	0.86
Dash Pnl	1	5.30	2.12	2.60	4.42	2.70	2.30
Roof Pnl	1	12.75	5.10	7.51	12.77	5.24	7.67
Rr End Upr Pnl	1	2.26	0.90	1.33	2.26	0.93	1.36
Qtr Innr Rr Pnl	2	1.02	0.41	0.50	0.85	0.52	0.44
Qtr Otr Pnl	2	9.63	3.85	5.68	9.66	3.95	5.81
W/H Otr	2	3.61	1.44	2.13	3.62	1.48	2.18
W/H Innr	2	4.85	1.94	2.97	5.05	1.88	3.11
Rr End Lwr	1	2.23	0.89	1.18	2.01	1.05	1.12
Compt Lid Otr	1	6.28	2.51	3.33	5.66	2.95	3.15
F/D Innr	2	6.62	2.65	3.24	5.51	3.38	2.86
F/D Outer	2	9.19	3.68	5.42	9.21	3.77	5.53
R/D Inner	2	5.65	2.26	2.77	4.71	2.88	2.45
R/D Outer	2	6.95	2.78	4.10	6.97	2.85	4.19
Frt Fndr	2	7.98	3.19	3.91	6.65	4.07	3.46
Hood	1	14.58	5.83	8.67	14.74	5.91	8.91
Flr Pnl	1	15.28	6.11	15.28	25.98		19.87
Compt Lid Innr	1	5.53	2.21	5.53	9.40		7.28
Mtr Compt Shk Hsg	2	3.98	1.59	3.98	6.77		5.18
Mtr Compt Sd Rt	1	0.93	0.37	0.93	1.58		1.21
Mtr Compt Sd Lt	1	1.31	0.52	1.31	2.22		1.71
Mtr Compt Sd W/H	2	3.77	1.51	3.77	6.41		4.90
Misc		2.79	1.12	2.79	4.74		3.62
		151.41	60.54	98.75	167.89	52.66	107.45

1 Steel 7.83 g/cm^3 $0.40/Kg
2 Aluminum 2.71 g/cm^3 $1.70/Kg

Table 2

IV IMPACT OF FABRICATION OPERATIONS

The substitution from CRS to aluminum would impact the fabrication plant's tooling, facilities and manpower costs as follows:

1. Increased Manpower

a. The use of aluminum creates problems in removal of protective materials in the form of edge protectors and separators from the sheets and coils prior to any cutting or forming operations.

b. Increased line maintenance on material handling equipment, increased line cleaning and die maintenance to eliminate surface damage.

c. Offal separation from steel. This may be accomplished auto matically, however, the system would require maintenance.

d. The increased possibility of process damage would increase the inspection required throughout the fabrication processes.

Estimated cost impact 25%

2. Increased Tooling Cost

Aluminum can be formed using the same equipment as steel, however, experience has shown greater care is required in making the dies and in some cases additional dies are required to obtain the required quality. Increased die maintenance, numbers of dies and associated equipment would affect the facility usage, set up

time, and secondary equipment usages.

Estimated cost impact 35%

3. Increased Material Handling Equipment

The ease with which aluminum surfaces can be damaged in the processing of the component requires special care and increased expenditures in the handling equipment. This can range from air stackers, increased and padded rollers, increased and larger vacuum lifters, redesigned die clearing tools, etc. The entire processing of some components may require revision to eliminate surface damage. Exposed surfaces that normally are processed with the exposed surfaces against conveyors would have to be processed with the exposed surface free of contact.

Estimated cost impact 20%

4. New Material Shipping Systems

Aluminum components shipped from fabrication to assembly plants will require newly designed shipping racks and containers. Where steel deck lids or hoods may be shipped on edge, aluminum components would be severely damaged. This item would vary greatly dependent on the banks required, shipping distance, the number of plants involved and line speed differences between fabrication and assembly.

Estimated cost impact 30%

5. Increased Scrap and Repair

With all the precautions that are taken it would be expected that a higher incidence of scrap and repair would be generated in the fabrication processes. The creation of special containers or shipping racks would require increased maintenance and if special separators are used automated systems or manpower to install the items would be required.
Estimated cost impact 10%

V. IMPACT ON ASSEMBLY OPERATIONS

Little information was available on the impact of aluminum on assembly plan operations and costs. The majority of information related to tip wear and recommended procedures in welding. These are of major importance, but don't addressthe many areas and costs that would be affected. All of the problems seen in the fabrication plant would be present in the assembly operations, plus a major impact in the body shop welding equipment, facilities, maintenance and repair areas.

1. Resistance Welding

Aluminum requires a higher current for welding than required for steel. Approximately three times when welding the same material thickness. The material is seldom substituted on a one to one material thickness basis, therefore, the welding current increase would be in excess of three times.

In welding aluminum a preliminary forging force is recommended to prepare for the weld. This force application is higher than the welding force and requires added controls and larger weld gun cylinders. The requirement for alternate gun application to the weld surface to prevent shunting also increases the control

systems and weld cycle time.

Structural adhesive bonding may alleviate some areas of difficulty, however, the technology is not adequate at this time to be considered reliable for structural components and high production rates. It is being used on secondary structural components such as doors, deck lids and hoods.

The increased power, pressure and control requirements would affect the following:

a. Facility power requirements and installations

b. Facility welder water installations

c Welder control systems

d. Increased transformer sizes

e. Weld gun cable size increase and increased use of water cooled jumpers.

f. Weld gun arm size increases

g. Increased tip wear

h. Increased cylinder sizes including use of sav-air or hydraulic systems.

i. Increased support equipment. The increased sizes of weld guns, cables, transformers, and gun arms would increase the number of welders to hold the multiple gun stations. Also the larger robotic systems would be required to manipulate the increased weight.

Estimated cost impact 40%

2. Material Handling.

The same problems faced in fabrication would be present in the assembly plant. Subassembly and assembly operation would require gaging, clamping, conveyors, and handling devices that would not damage exposed surfaces or mutilate weld flanges. Once designed and built greater maintenance costs will be incurred.

Estimated cost impact 25%

3. Repair and Surface Finish

An area not covered in abailable materials is the effect of any repairs or joint finishing that will require a filler material. With steel bodies solder is used that requires minimal line space for application and set up. For aluminum, epoxy fillers are required that require a large line space plus heaters to cure for finish. At 60 units/hour and 20 foot line spacing a 600 foot line area would be consumed for curing when a half hour is required. Also, like solder, the epoxies require special booths for grinding with operator hoods and make-up air to prevent respiratory diseases.

Standard tools are required for the surface finishing of aluminum, however, with its susceptability to damage increased finish operations would be expected. Secondary problems occur with paint cycles as the filler and body expand at different rates and the repair or finished joint develops a crack around the perimeter.

The joint problems can be reduced in the vehicle design.

Estimated cost impact 20%.

4. Scrap Increase.

The susceptability of aluminum bo be damaged in sub assembly and line operations will increase the scrap that will be generated. Where steel panels may be repaired and used aluminum may have to be scrapped as the most economical method.

Estimated cost impact 5%

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APPENDIX M

AVSIZING COMPUTER PROGRAM
ADVANCED VEHICLE ENERGY PROGRAM (AVEnergy)
ADVANCED VEHICLE COST PROGRAM (AVCost)

AVSIZING COMPUTER PROGRAM

M.A. Gyamfi
S.A. Herman

1.0 INTRODUCTION

AVSIZING is a computer program written for the IBM Personal Computer on the IBM version of Microsoft BASIC. The purpose of AVISZING is to size a preliminary vehicle and (at the user's request) write to disk input files to the ELVEC computer program and also input files with partial sets of inputs to the programs AVENERGY and AVCOST. (AVENERGY and AVCOST are written in BASIC for the IBM Personal Computer).

In running AVSIZING the user has the following options:

1. Size a new vehicle targeted to a desired range. This logic allows for multiple passes and when a satisfactory vehicle is sized the user may generate an ELVEC input file using one of the 3 cycles:
   a. Federal
   b. Highway
   c. Van

2. Generate a 24-hour cycle input file for ELVEC using a previously-sized vehicle. (This vehicle may have been sized using option 1 or option 3.)

3. Redesign a vehicle previously sized by option 1 by changing the battery mass fraction (BMF).

2.0 PROGRAM STRUCTURE

For any run, whether it is a run to size a new vehicle or a redesign of a previous vehicle, the following basic set of variables must be defined.

a. Is the vehicle electric or hybrid?

b. Battery type chosen from the following list:

   1. AL-AIR
   2. FE-AIR
   3. LI-FE-S
   *4. LI-FE-S2
   5. NA-S
   6. NI-FE
   7. NI-ZN
   8. PB-AC/ADV
   9. PB-AC/BIPL
   10. ZN-BR
   11. ZN-CL2

* LI-FE-S2 is not currently operational

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c. Power to energy ratio from the following list:

1. P/E = 1.0
2. P/E = 2.1
3. P/E = 2.4
4. P/E = 3.3

From the values of b and c, a valid battery name for the ELVEC program is constructed, e.g., FE-AIR2.4.

Some of the batteries have a single name independent of the power to energy ratio. These names are:

1. AL-AIR
2. NI-ZN2.0
3. PB-AC/BIPL

Some of the batteries names are the same for the power to energy ratios of 2.1 and 2.4 and are given the 2.1 designation. These names are:

1. LI-FE-S2.1 (also 2.4)
2. NI-FE 2.1 (also 2.4)
3. PB-AC/AD2.1(also 2.4)

The fusion of names occurs because in ELVEC these batteries have the same specific power X cutoff DOD tables. This implies that the user must provide CH-coefficients and other battery data whenever the battery with the omitted power to energy ratio is used. AVSIZING supplies its own battery data (including CH-coefficients) for each power to energy ratio.

2.1 THE RANGE EQUATIONS

For each battery and power to energy ratio there is a set of coefficients A,B which define the BMF as a function of ELVEC range. (A and B are part of the battery data set). The equations are given by:

$$BMF = (A*R + B)/100$$

where R is the ELVEC range.

These equations are used only when running a new vehicle targeted to a desired range. Because of recent changes made to ELVEC after A and B were determined, they probably should be rederived.

2.2 NUMBER OF CYCLES FOR 5-PASSENGER VEHICLES

When running a 24-hour cycle, the number of cycles used is dependent upon the desired ranges for the 5-passenger vehicle.

The choices are:

1. 100 mi. (uses 10 cycles)
2. 150 mi. (uses 11 cycles)
3. 250 mi. (uses 12 cycles)

2.3 MOTOR TYPE

Only the AC option is currently operational although some coding for a DC option is in place.

2.4 BATTERY DATA SETS

AVSIZING Supplies the following information for each battery:

a. battery name
b. the variables ---
   1. EFFCK
   2. SLFD
   3. ACC
c. The coefficients of the range equations i.e., A,B
d. constants in the volume equations Q1, Q2 and the battery power equation PBC.
e. The CH-coefficients.

2.4 VEHICLE PARAMETERS

The values for grade power (GRADE) cycle power (CYCLE) and acceleration power (ACCN) are given in the following table.

CAPACITY	GRADE	CYCLE	ACCN*
2	17.5	25.9	21.5
4 or 5	28.0	26.0	24.0
6	20.3	20.3	20.3

* unit is w/kg for GRADE, CYCLE and ACCN

The following parameters are used in the equation for test weight (see next section).

```
WMOT1   = 0.9* GRADE/MOTSW
WCON1   = X1/CONSW
WTF1    = X1/TRFSW
WHE1    = GRADE/HESW (for hybrid)
WTCVT1  = GRADE/TRCVTSW (for hybrid)
WTR1    = WTF1 (for electric)
          WTF1 + WTCVT1 (for hybrid)
```

where for capacity 2 or 6 we have

X1 = cycle

and X1 = GRADE otherwise.

The various constants in the above equations are given below:

MOTSW	= 490
CONSW	=2500
TRFSW	=1418
TRCVTSW	=1096
HESW	= 450

2.5 THE WEIGHT EQUATIONS

The unit of weight is kilograms, volume is liter and power is kilowatt unless otherwise noted.

The basic equation is:

WT = WSH + PANDPL + 1.3 (SUM)

where

WSH is the shell weight
PANDPL is passenger and payload weight

and SUM is given by

SUM = WB + WMOT1*WT+WCON1*WT+WTR1*WT+WHE1*WT

where

WT is the test weight
WB is the battery weight

The remaining terms were defined in the previous sub-section.

Using the definition WB = BMF*WT and solving for WT we obtain:

WT = WTERM1/(1-1.3(WTERM2))

where

WTERM1 = WSH + PANDPL

and

WTERM2 = BMF+WMOT1+WCON1+WTR1+WHE1

The curb weight (WC) is the given by

WC = W + PANDPL

The motor weight (WMOT) is given by

WMOT = (0.9* GRADE/MOTSW)* WT

The weights of the controller (WCON) fixed transmission (WTF), EVtransmission power and controller power (CKW) are summarized by the equations:

```
CKW   = X1/1000
WCON  = X1/CONSW
STF   = X1/TRFSW
ETKW  = X1/1000
```

Where for capacity 2 or 6 we have

```
    X1 = CYCLE*WT
and X1 = GRADE*WT otherwise
```

Further, if the vehicle is a hybrid we have:

```
WTCVT   = (GRADE/TRCVTSW)* WT
EPOW    = ( GRADE*WT)/1000
ENGHP   = EPOW/.746 (horsepower units)
ENGKW   = EPOW      (kilowatt units)
WHE     = (GRADE/HESW)*WT
PEFPWR  = 0.9*GRADE*WT/1000
```

where

WTCVT is the weight of the CVT
EPOW is the ICE transmission power
ENGHP the engine power in horsepower
ENGKW is the engine power in kw.
WHE is the weight of the heat engine
PEFPWR is the motor power

The volumes are computed by the following equations:

```
VMOT  = PEFPWR/1.54
VCT   = CKW/2.15
VTTIF = ETKW/2.8
```

For hybrids only

```
ENGVOL   = EPOW/.5
GTRANVOL = ETKW/2.8
```

where

VMOT is the motor volume
VCT is the controller volume
VTTIF is the EV transmission volume
ENGVOL is the engine volume
GTRANVOL is the ICE transmission volume

The volume of the batteries (BVOL) is given by:

BVOL = (Q1*WB)/Q2

Where Q1 and Q2 are part of the battery data sets

The battery power (PB) is given by:

PB = (PBC*WB)/1000

Where PBC is part of the battery data sets.

All of the above weight-dependent variables are computed in subroutine WEIGHT.

2.6 ITERATION PROCEDURE FOR ACTUAL RANGE.

From the desired range (DRAN) which is input by the user, an estimate of the ELVEC range (R) is made:

R = 1.2* DRAN

The iteration procedure begins by using the range equation to compute BMF.

BMF = (A*R+B)/100

The specific power (WKG) is now computed

WKG = ACCN/BMF

Call subroutine ACTUAL RANGE where a cutoff DOD is determined and an actual range (ACTRAN) is computed by the equation

ACTRAN = DOD*R/100

If the actual range is within 5% of the desired range then the iteration procedure is terminated. If not, then the ELVEC range (R) is updated by the factor DRAN/ACTRAN and the BMF is computed beginning another iteration. The upper limit to the number of iterations is now set to 30.

2.7 DOMINANT BMF

The power density is given by

PD = EXP(LPD)

where

$$LPD = CH(1) + CH(2)\ LOG\ (TAU) + CH(3)^* (LOG(TAU))^2$$

and TAU = 6.6/60

If GRADE/PD BMF and the BMF is not input by the user, then the dominant BMF is "GRADE". Otherwise, the dominant BMF is "RANGE". For the case where the user enters the BMF (the redesign option) then the dominant BMF is "INPUT".

2.8 THE AVSIZING OUTPUT REPORT

The AVSIZING output report contains the following information:

a. Vehicle capacity
b. Vehicle type
c. Desired Rage
d. Dominant BMF
e. Battery name
f. BMF
g. Test weight
h. Actual range (est)

In addition, the weight (kg) and power (kw) are given for:

a. Motor
b. Controller
c. EV transmission
d. Battery
e. ICE transmission
f. Engine

A sample output report follows:

```
                         AVSIZING OUTPUT REPORT
                         ----------------------

Range converged in  2 iterations.

        TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC

                                                WT(KG)      VOL(LTR)     PWR(KW)
THE VEHICLE CAPACITY IS   5
THE VEHICLE TYPE IS ELECTRIC          MOTOR      90.35        28.75        44.27
THE DESIRED RANGE IS 100.00 MI        CONTR      19.68        22.88        49.19
THE DOMINANT BMF IS RANGE          EV TRANS      34.69        17.57        49.19
THE BATTERY IS NI-FE1.0               BATTR     489.02       268.48        58.68
                                  ICE TRANS       0.00         0.00         0.00
                                     ENGINE       0.00         0.00         0.00

THE BMF IS                 0.278
THE TEST WEIGHT IS      1756.86 KG
THE CURB WEIGHT IS      1620.86 KG
THE ACTUAL RANGE IS      101.56 MI

                    **END OF PROGRAM OPERATIONS**
```

2.9 PURPOSE OF SUBROUTINES

SUBROUTINE	PURPOSE
FRONT-END	Writes statement to disk that when sent to the VAX will create (open) the appropriate file. Writes the initial portion of the various cycles to disk. This subroutine is used by all cycles (Federal Highway, Van, and 24-hr.
PARAMVAR	Writes further statements for the various cycles to disk.
CYCLE - I (I=1 to 12)	Writes the individual cycles (1-12) to disk for the 24-hr. cycle.
CYCLE-VAN	Writes portion of VAN cycle to disk.
VEHICLE-DATA	If not running a 24-hr. cycle, writes vehicle data to disk. It is called after a non-24-hr. cycle is written to disk. The file written by this subroutine is read only if a new vehicle is not being run.
CH-READ	Reads the CH-coefficient from data statements.
BATN$-READ	Reads battery names from data statements.
ACTUAL-RANGE	Contains the cutoff DOD vs. specific power tables. Computes actual range.
WEIGHT	Computes weight-dependent quantities.
HYBRID	Writes hybrid inputs to ELVEC program to disk.
DATA	Writes data for ELVEC program to disk.

AVSIZING USER'S GUIDE

1.0 PRELIMINARIES

It is assumed that the SMARTCOMII communication package disk (Hayes Microcomputer Products Corp.) with a macro set for automatic log on is inserted in drive A. Drive B is reserved for a disk containing the programs: AVSIZING. BAS, AVENERGY.BAS and AVCOST.BAS. Normally the disk in drive A is used to boot the system.

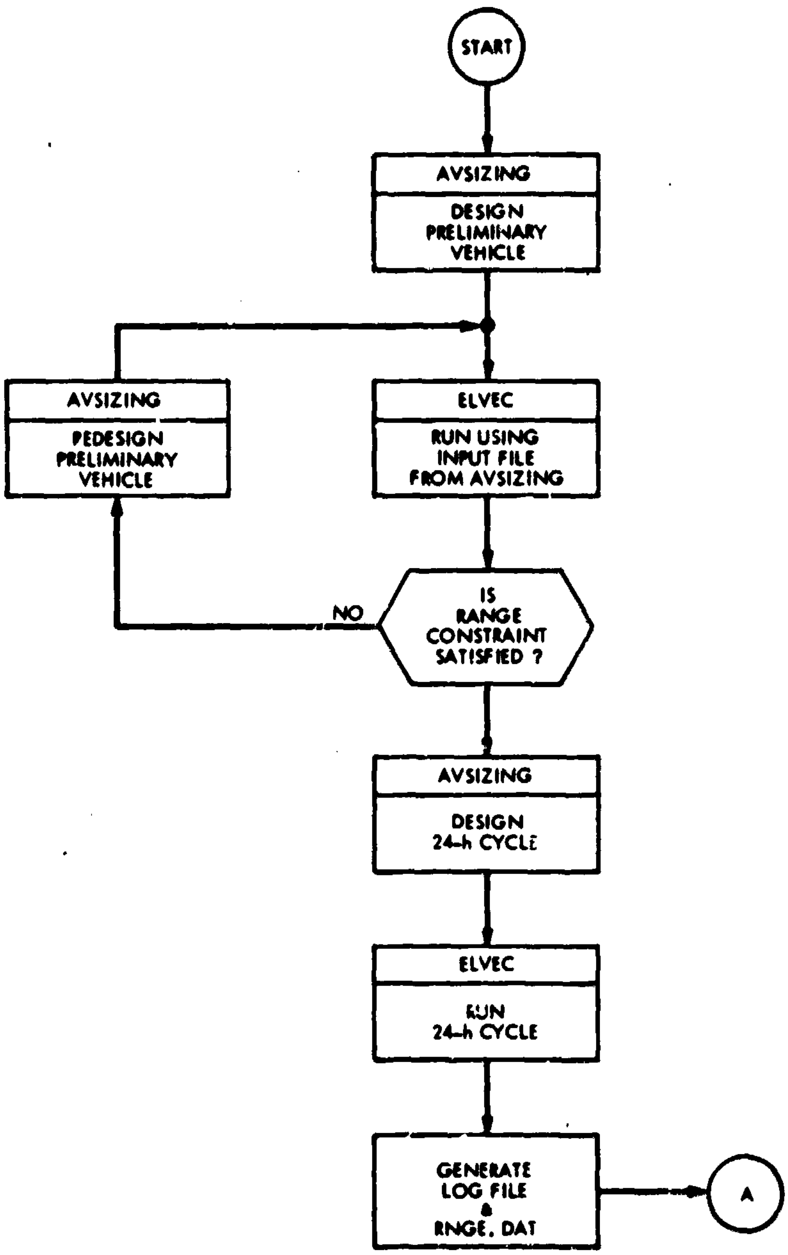

Figure M-1. Design Procedure Flow Diagram

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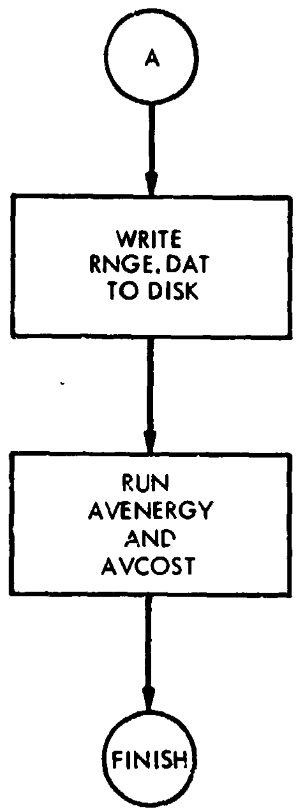
A
WRITE
RNGE.DAT
TO DISK
RUN
AVENERGY
AND
AVCOST
FINISH

3.0 OUTLINE OF DESIGN PROCEDURE TERMINAL SESSION

This section steps through the design of a preliminary vehicle, 24-hour cycle and running of the energy and costing programs. Each step is numbered and represents an action taken by the user. The actions indicated are entered at the keyboard. Non-specific actions are braketed and are not numbered. Comments are also braketed or enclosed in parenthesis or explicitly labeled.

3.1 PHASE 1 (design preliminary vehicle)

STEP	ACTION	RESULT
	(prompt = A>)	IBMPC
1.	B:	Change to B drive.
2.	BASIC AVSIZING	Request version of basic, load and run AVSIZING.
	[Respond to prompts in AVSIZING]	Comment: In this case AVSIZING is used to size a preliminary vehicle.
3.	SYSTEM	Return to system.
4.	A:	Change to A drive
5.	SCOM	Activate SMARTCOM II
6.	B	Set directory for the B drive.
7.	↵	Begin communications
8.	↵	originate transmission
9.	↵	dial
	[Macro is activated for automatic log on.]	
	(prompt = $)	VAX environment)
	[Ready to send file LOCAL.DAT to VAX]	
10.	F1	Display SMARTCOM menu

STEP	ACTION	RESULT
11.	7 (optional)	printer on
12.	5	send file
13.	2	start/stop protocol
14.	LOCAL.DAT [Wait until transmission of file is complete.]	Enter file name
15.	control Z	Completes the creation of the file STAREL.COM
16.	@MAX* run	Execute MAX.COM to run ELVEC in demand mode.
17.	NO (normally) or YES	Response to question: do you wish to see 1 July message?
18.	↵ (normally)	Response to: BULK DATA FILE TO BE USED (NULL RETURN FOR DEFAULT):
	[The command file STAREL.COM will supply automatic inputs to the ELVEC program until run is completed.]	
	(prompt = $)	(VAX environment)
19.	LOG	log off
20.	F1	Display SMARTCOM menu

---

* It is assumed that ELVEC is to be run in demand. If you wish to run ELVEC in batch (the correct response to question in AVSIZING must have been given) replace @MAX with SUBMIT STAREL.COM/NO PRINT/QUE= FIFO.

STEP	ACTION	RESULTS
21.	0	end communications/ program
22.	Y	Response to question: Exit program?

(prompt = A>)

[Repeat above sequence (steps 1-22) until range constraint is satisfied.]

3.2 PHASE 2 (generate 24-hour cycle)

STEP	ACTION	RESULT
	[repeat steps 1-9]	Comment: In this case AVSIZING is used to generate a 24-hr. cycle
	[Macro is activated for automatic log on]	
	(prompt = $)	
	[Ready to send file XXX.DAT (batch) or STAREL.DAT (demand)]	
	[repeat steps 10-13]	
23.	XXX.DAT (for batch) or STAREL.DAT (for demand) (XXX is file name of 24-hr. input file)	Enter file name
	[Wait 'till transmission of file is complete.]	
24.	Control Z	Completes creation of appropriate file.
	[If batch mode then XXX.COM is created. If demand mode then STAREL.COM is created.]	
25.	@MAX (for demand) or	run ELVEC (in demand or batch)

STEP	ACTION	RESULTS
	SUBMIT XXX.COM/NOPRINT/ QUE=FIFO (for batch)	
	[if demand mode respond to first two prompts. (steps 17 and 18)]	
	(prompt = $)	VAX
	[repeat steps 19-22]	
	(prompt = A>)	IBMPC

After running ELVEC with a set of inputs for a 24-hour cycle a VAX file named RNGE.DAT is created. This file contains a partial set of inputs for the IBMPC program AVENERGY.BAS. Therefore, this file (or at least a portion of it) must be written to disk. This is done as follows:

STEP	ACTION	RESULT
	(prompt = $)	(VAX environment)
26.	TYPE RNGE.DAT ** <u>but do not enter</u>.	prepare to type RNGE.DAT
27.	F4	Receive file
28.	↵	complete typing of RNGE.DAT
29.	F1	Completes file reception
	[enter file name to be used on disk in B drive (This is optional since default = TEMP) SMARTCOM must be set for B directory).]	Rename file (This file is called the ELVEC OUTPUT FILE in AVENERCY.BAS)
	[repeat steps 19-22 (prompt = A)]	

---

* For simplicity it is assumed that RNGE.DAT contains only the inputs for the current run. The case where this is not true will be discussed in section 4.

If ELVEC is run in batch, a file XXX.LOG is created which contains the result of the run. (XXX is the file name of the 24-hour input file.)

The user is now ready to run the programs AVENERGY and AVCOST. Nearly all of the input procedure has been made automatic, however, each of these programs prompts the user for some information. Part of the inputs are the names of files on disk which contain data for these programs. These files are:

XXX.ENG	(input to AVENERGY)
ELVEC OUTPUT FILE	(input to AVENERGY)
XXX.COS	(input to AVCOST)
ENERGY.DAT	(input to AVCOST -- but not requested. This file is created by AVENERGY.)

IMPORTANT: AVENERGY and AVCOST must be run in tandem.

The following section will discuss these and other files on disk in more detail.

4. FILES ON DISK

This following is a list of all the files on disk (B drive) generated or used by the various programs.

<u>1 ELVEC OUTPUT FILE</u> (Actual name specified by user)

This file contains information required by AVENERGY that is created when ELVEC is run for a 24-hour cycle. It is a copy on disk of all or a part of the file RNGE.DAT created in the VAX environment. The user specifies its name when down loading RNGE.DAT (all or part) to disk. If a name is not specified, the default name is TEMP.

If RNGE.DAT is not erased before running a 24-hour cycle, then the data contained in RNGE.DAT may be stacked for several runs. The data in the ELVEC OUTPUT FILE must contain the data for a single run. This can be accomplished by creating another file, i.e. XXX.RAN, which contains only the required information. The procedure is as follows:

1. Copy RNGE.DAT to XXX.RAN
   (the command is: COPY RNGE.DAT XXX.RAN).

2. Delete unwanted lines using the VAX editor.

3. Download XXX.RAN to disk.

The data in the ELVEC OUTPUT FILE are:

ELVEC range	(one for each cycle)
Actual range	(one for each cycle)

Maximum DOD	
Maximum PD	
Energy consumption	(one for each cycle)
gal. per mi	(one for each cycle)
date	
time	(one for each cycle)

AVENERGY Requests the name of the ELVEC OUTPUT FILE in order to obtain the above information. If the user responds to this request with a carriage return (null response) then this allows the user to input the information from the keyboard.

2. ENERGY.DAT

This file is created by AVENERGY and transfers information to AVCOST.

The data are:

In AVENERGY	In AVCOST
ETKM	TKM
E	AELC
ENER	EOLY
FUEL	RICE
DCON	KMYR
LITM	AFUS
BCL	CYCB
X365	ADOD
WB	WB
TIT$	PHD$
VEH	IVTYP

3. LOCAL.DAT

This file is the local file (on disk) created by AVSIZING whenever a new vehicle is being designed. It is also created when the redesign option is used. It is sent to the VAX where it creates a file called STAREL.COM which contains the inputs for the ELVEC program. (STAREL.COM is called the remote file). STAREL.COM may be used to run ELVEC in demand or batch mode.

4. STAREL.DAT

This is the local file (on disk) for running a 24-hour cycle in demand. The remote file is STAREL.COM. This file is created by AVSIZING.

5. XXX.COS (XXX is file name of 24-hour input file)
This file is created by AVSIZING. It contains data required by AVCOST.

The data are:

IN AVSIZING	IN AVCOST
PEFPWR	MKW
CKW	CKW
ETKW	ETKW
EPOW	EPOW
NAM$	BATTS
WC	CURBWT

6. XXX.DAT (XXX is file name of 24-hour input file)
This file is created by AVSIZING. It is the local file (on disk) for running a 24-hour cycle in batch. The remote file is XXX.COM.

7. XXX.ENG (XXX is file name of 24-hour input file)
This file is created by AVSIZING. It contains data required by AVENERGY. The data are:

IN AVSIZING	IN AVENERGY
WB	WB
WT	WT
TLE$	TIT$
VEH%	VEH

8. VEHICLE.DAT

This file is created by AVSIZING and is used to transfer information from a new vehicle design to a redesign, or 24-hour cycle option. AVSIZING is the only program which uses the data in this file.

SAMPLE CASE

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1.0 SAMPLE CASE

The vehicle used in this sample has the following parameters:

1. 5-passengers
2. electric
3. battery is NI-FE1.0
4. desired range is 100 miles

2.0 SIZING NEW VEHICLE USING AVSIZING

The federal cycle was used along with the inputs given above to size a preliminary vehicle.

The local file (on disk) LOCAL.DAT was created by AVSIZING using the demand mode option. Sending LOCAL.DAT to the VAX created the file in the VAX environment STAREL.COM. Executing the command file MAX.COM then ran ELVEC in the demand mode.

2.1 RUNNING 24-HOUR CYCLE

AVSIZING was used to generate a 24-hour cycle corresponding to the preliminary vehicle indicated above. The file name of the 24-hour input file was chosen to be ELTEST.

This created the following files on disk:

ELTEST.DAT
ELTEST.ENG
ELTEST.COS

ELTEST.DAT was sent to the VAX in order to create the file ELTEST.COM which was used to run ELVEC in the batch mode. This, in turn created the files (in the VAX environment):

ELTEST.LOG
RNGE.DAT

RNGE.DAT was down loaded to disk under the name ELTEST.RAN.

3.0 RUNNING AVENERGY

The inputs for this sample case are:

FILE OF THE FORM XXX.ENG	ELTEST.ENG
ELVEC OUTPUT FILE	ELTEST.RAN
VEHICLE NUMBER	3
BATTERY CYCLE LIFE	750

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PAGE M-28 INTENTIONALLY BLANK

4.0 RUNNING AVCOST

The inputs for this sample case are:

FILENAME OF THE FORM XXX.COS	ELTEST.COS
COST OF ELECTRICITY IN C/KW-H	5
BATTERY SHELF LIFE IN YEARS	10
DEPTH OF DISCHARGE	0.8
MAINTENANCE FACTOR	1
LIFE OF VEHICLE IN YEARS	10
MOTOR TYPE	1
CONTROLLER TYPE	1
SALVAGE VALUE (%)	10
REAL INTEREST RATE (%)	10
REAL DISCOUNT RATE (%)	10
FINANCE TERM IN YEARS	4
EV TRANSMISSION TYPE	1

The computer output for this sample case starting with the AVSIZING output report for the preliminary vehicle and ending with the results of AVCOST follows.

```
                          AVSIZING OUTPUT REPORT
                          ----------------------

Range converged in  2 iterations.

        TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC

                                                WT(KG)     VOL(LTR)    PWR(KW)
THE VEHICLE CAPACITY IS   5
THE VEHICLE TYPE IS ELECTRIC         MOTOR      90.35       23.75       44.27
THE DESIRED RANGE IS 100.00 MI       CONTR      19.68       22.88       49.19
THE DOMINANT WMF IS RANGE         EV TRANS      34.69       17.57       49.19
THE BATTERY IS NI-FE1.0              BATTR     489.02      268.48       58.68
                                 ICE TRANS       0.00        0.00        0.00
                                    ENGINE       0.00        0.00        0.00

THE BMF IS              0.278
THE TEST WEIGHT IS    1756.86 KG
THE CURB WEIGHT IS    1620.86 KG
THE ACTUAL RANGE IS    101.56 MI

                       **END OF PROGRAM OPERATIONS**
```

```
CREATE/LOG STAREL.COM
E
N
N
N
USERDATA
ADVEV
MULMOT ANALYT
MULBAT ACIRNG                                        ◄(LOCAL.DAT)
NAMBAT NI-FE1.0
NAMCYC FEDRAL
RUN
N
SLFDSC .016
ECHO ON
PACC 0
WT 1756.86
WB 489.0176
CDA .6
CRDIAL 1
PTIRE 30
PEFPWR KW 44.27207  44.27207
PMXANL W8.54573KW
PKEFF .95  .95
EFFCD .50
CM 3.05054 -.723694 -9.85473E-03
END
TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC
N
QUIT
^Z

%CREATE-I-CREATED, SIAO:[ORCUSER]STAREL.COM;598 created        (RUNNING ELVEC
                                                              ◄ IN DEMAND MODE
$ @MAX                                                          WITH MAX MAX.COM)

Do you want to see 1 July message? :

BULK DATA FILE TO BE USED(NULL RETURN FOR DEFAULT)? :

ORC ELECTRIC VEHICLE/BATTERY SIMULATION.  VERSION 8.4  16APR84
 SPECIFY DESIRED OUTPUT UNITS - METRIC OR ENGLISH . . .
>
INITIATING BULK READ...DO YOU WANT TO SEE INTRODUCTORY PRINTOUT(Y OR N)?
>
BULK READ COMPLETE-
GEETV1      OEMIDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
DO YOU WANT CARD IMAGES OF SPECIAL DATA PRINTED (Y OR N)?
>
EV2-13/A    BATIDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
DO YOU WANT CARD IMAGES OF SPECIAL DATA PRINTED (Y OR N)?
>
 INPUT CHANGES FOR NEXT RUN-
>
NAME OF DATA PACKAGE...
>
WT 1060 WB 166 CDA 0.555 CRDIAL 0.85
NAMCYC FEDRAL NREGEN 2 VMINRG 5MPH ACLFAC 0.5 ACLRCS 1.5MPH
```

```
NAMHYB EV
MDLBAT FRCTUT NAMBAT AL-AIR
MDLMOT ANALYT PKEFF 0.9 0.9 EXPTRQ 0.15 0.15 PEFOMD RPM 10000 10000
PEFPWR KW 20 20
NAMCLC DRCOUP RATIO .282 16 GEAR 1 1 1 1
VELSCD 300 300 300 SHFDWN 300 300 300 EFFCT 0.9 0.9 0.9 0.9
DELT 1 TSTOP 20000
END DATA
>
>
>
>
>
 INPUT COMPLETE FOR THIS CASE
NI-FE1.0   BATTDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
DO YOU WANT CARD IMAGES OF SPECIAL DATA PRINTED (Y OR N)?
>
 VALUE DEFINED FOR UNIT NAME  SCLF  -
NEW DATA READ IN TABLES...OVERRIDE, IF NECESSARY
>
>
>
PACC 0
>
WT 1756.86
>
WB 489.0176
>
CDA .6
>
CRDIAL 1
>
PTIRE 38
>
PEFPWR KW 44.27287  44.27287
>
PMXANL 88.54573KW
>
PKEFF .95  .95
>
EFFCD .58
>
CH 3.85854 -.723694 -9.85473E-03
>
END
 INPUT COMPLETE FOR THIS CASE
 INPUT A 1-78 CHARACTER TITLE FOR THIS CASE-
>


TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC
DATE   28-SEP-84
TIME   08:31:26

FEDRAL     SCHDDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
FEDRAL CYCLE. 1372 VALUES READ.
```

```
KEY PARAMETERS (METRIC UNITS)
  ------------VEHICLE------------  -----------STRATEGY-----------
   WB    WT    CDA   TTIRE PTIRE  ACLFAC  ACLRCS  FBRKS  NREGEN  EFFCM  EFFCFW
   489  1757  0.600  RADIAL 38.0   0.50   -0.67    0.30    2     0.000  0.565

--------------MODELS------------------
DRCOUP  ANALYT  NI-F&1.0     EV

SCHEDULE  PERIOD  RANGE  AVERAGE  ROAD  ENERGY  MAX ROAD
                          SPEED  W/O RGN  W RGN  POWER
          SEC      MI     MI/H      WH/MI          HP
  FEDRAL  1371   7.450    19.6   202.4     97.6    50.6

ENERGY AND EFFICIENCY SUMMARY FOR RANGE TRAVELED-
-------------------------------------------------------------------------------
  MAJOR SUBSYSTEM LOSSES AND EFFICIENCIES-
                     BATT SYS   MTR/CNT   DRVTRN    PWRTRN    BRAKES     MISC
   WH/MI              227.5      37.9      30.3      68.3      34.6       0.4
    PRCNT(PWRTRN)     333.2      55.6      44.4     100.0      50.7       0.6
    PRCNT(OVERALL)     53.1       8.9       7.1      15.9       8.1       0.1
   EFFICIENCY         0.528     0.881     0.898     0.793
-------------------------------------------------------------------------------

  COMPONENT LOSS BY DRIVING PHASE(WH/MI AND PERCENT OF OVERALL)-
                      TOTAL     ACCEL     CRUISE    COAST     BRAKE      DWELL
  OVERALL,WH/MI       428.4
   EFFICIENCY         0.309
  MOTOR                37.9      23.7       2.3       0.0      11.9        0.0
   PERCENT              8.9       5.5       0.5       0.0       2.8        0.0
   EFFICIENCY         0.881     0.893     0.871     0.000     0.850      0.000
  TRANSMISSION         30.3      19.5       1.7       0.0       8.8        0.0
   PERCENT              7.1       4.6       0.4       0.0       2.1        0.0
   EFFICIENCY         0.898     0.895     0.895     0.000     0.895      0.000
  AERO                 36.0      14.8       5.6       0.0      15.7        0.0
   PERCENT              8.4       3.4       1.3       0.0       3.7        0.0
  TIRES                61.6      27.6       7.6       0.0      26.5        0.0
   PERCENT             14.4       6.4       1.8       0.0       6.2        0.0
  MISCELLAN             0.4       0.2       0.0       0.0       0.1        0.1
   PERCENT              0.1       0.0       0.0       0.0       0.0        0.0

  ---------------------BATTERY AND CHARGER--------------------
  -------ENERGY------    POWER,MX   FINAL   BATT   -----CHARGER-----
  OUT   IN   LOSS        OUT   IN   STATE   EFF       LOSS       EFF
   WH/MI  WH/MI PRCNT       W/LB                    WH/MI PRCNT
  255   54   185  43.1   41.2  16.9  0.000  0.58    43 10.00   0.900

    TOTAL       ELECT CONSM       ELECT COST
    RANGE         AT WALL       (AT 10.0C/KWH)
     MI       WH/MI  WH/MI*TON       C/MI

    130.9     428.6    221.3         4.29
    103.9 *

 * - BASED ON LOWEST DEPTH OF DISCHARGE ( 0.794)WHICH COULD
     SUSTAIN THE MAXIMUM POWER DENSITY (   90.9 W/KG).

 EQUIVALENT FUEL CONSUMPTION AND ECONOMY (GASOLINE)-

   SOURCE OF        CONSUMPTION      ECONOMY
  PRIMARY ENERGY      LIT/KM      KM/LIT   MI/GAL
    PETROLEUM        0.07698       13.0     30.6
    COAL             0.04450       22.5     52.8

DO YOU WANT THE CAFE VALUE COMPUTED?
>
N

*******************************************************************************

 INPUT CHANGES FOR NEXT RUN-
>
QUIT
```

ORIGINAL PAGE IS
OF POOR QUALITY

AVSIZING OUTPUT REPORT

Range converged in 2 iterations.

TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC

		WT(KG)	VOL(LTR)	PWR(KW)
THE VEHICLE CAPACITY IS 5				
THE VEHICLE TYPE IS ELECTRIC	MOTOR	90.35	28.75	44.27
THE DESIRED RANGE IS 100.00 MI	CONTR	19.68	22.88	49.19
THE DOMINANT BMF IS RANGE	EV TRANS	34.69	17.57	49.19
THE BATTERY IS NI-FE1.0	BATTR	489.02	268.48	58.68
	ICE TRANS	0.00	0.00	0.00
	ENGINE	0.00	0.00	0.00

THE BMF IS 0.278
THE TEST WEIGHT IS 1756.86 KG
THE CURB WEIGHT IS 1620.86 KG
THE ACTUAL RANGE IS 101.56 MI

END OF PROGRAM OPERATIONS

C-5

```
AN INPUT FILE HAS BEEN WRITTEN TO DISK USING THE 24 HOUR CYCLE AND DATA FROM THE
 LAST RUN FOR WHICH A FEDRAL, HIGHWAY, OR VAN INPUT FILE WAS CREATED



YOU WISH TO RUN THE 24 HR. CYCLE IN BATCH THEREFORE:
   THE LOCAL FILE IS ELTEST.DAT
   THE REMOTE FILE IS ELTEST.COM
   THE SUBMIT COMMAND IS SUBMIT ELTEST.COM/NOPRINT/QUE=FIFO



                       ** END OF PROGRAM OPERATIONS **


                            TYPE RUN TO RE-START
```

```
CREATE/LOG ELTEST.COM
$ SIA0:[GRCUSER.STORE]RUNELVEC
$

E
N
N
N
USERDATA
ADVEV
MDLMOT ANALYT
MDLBAT ACTRNU
NAMBAT NI-FE1.0
PARAMVAR
NAMCYC
N
URB1 1 URB2 1
park 1.9hr
URB3 1 URB4 1 URB5 1 URB6 1 URB7 1 URB8 1
park 21.90hr
END
RUN
N
SLFDSC .016
ECHO ON
PACC 0
WT 1756.86
WB 489.0176
CDA .6
CRDIAL 1
PTIRE 38
PEFPWR KW 44.27287  44.27287
PMXANL 88.54573KW
PKEFF .95  .95
EFFCD .58
CH 3.85854 -.723694 -9.85473E-03
END
TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 1
N
PARAMVAR
NAMCYC
N
URB1 1 URB2 1 URB3 1 URB4 1 URB5 1 URB6 1
park 5.01hr
URB7 1 URB8 1 URB9 1 URB10 1 URB11 1 URB12 1 URB13 1 URB14 1 URB15 1 URB16 1
URB17 1
park 18.60hr
END
RUN
TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 2
N
PARAMVAR
NAMCYC
N
URB1 1
park 5.16hr
URB2 1 URB3 1 URB4 1 URB5 1 URB6 1
park 0.75hr
URB7 1 URB8 1 URB9 1 URB10 1 URB11 1 URB12 1 URB13 1 URB14 1 URB15 1 URB16 1
URB17 1
```

◄(ELTEST.DAT)

```
park 2.77hr
URB1 1 URB2 1 URB3 1 URB4 1 URB5 1 URB6 1
URB7 1 URB8 1 URB9 1
park 14.73hr
END
RUN
TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 3
N
PARAMVAR
NAMCYC
N
fedral 1
park 0.95hr
URB2 1
park 3.44hr
fedral 1
park 18.79hr
END
RUN
TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 4
N
PARAMVAR
NAMCYC
N
URB1 1 URB2 1 URB3 1 URB4 1 URB5 1 URB6 1
park 7.15hr
URB7 1 URB8 1 URB9 1 URB10 1 URB11 1 URB12 1 URB13 1 URB14 1 URB15 1 URB16 1
URB17 1
park 1.56hr
fedral 1
park 6.87hr
fedral 1
park 7.20hr
END
RUN
TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 5
N
PARAMVAR
NAMCYC
N
fedral 2
park 1.04hr
URB1 1 URB2 1 URB3 1 URB4 1 URB5 1 URB6 1
URB7 1 URB8 1 URB9 1
park 0.87hr
URB1 1 URB2 1
park 6.83hr
URB3 1 URB4 1 URB5 1 URB6 1 URB7 1 URB8 1 URB9 1 URB10 1 URB11 1
URB12 1 URB13 1 URB14 1 URB15 1 URB16 1 URB17 1
park 1.63hr
fedral 1
park 11.89hr
END
RUN
TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 6
N
PARAMVAR
NAMCYC
N
fedral 2
```

```
park 4.57hr
URB1 1
park 0.60hr
fedral 2
park 2.57hr
fedral 1
park 1.38hr
fedral 1
park 12.55hr
END
RUN
TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 7
N
PARAMVAR
NAMCYC
N
fedral 2
park 0.82hr
fedral 2
park 0.15hr
fedral 2
park 3.73hr
URB1 1 URB2 1
park 0.216hr
URB3 1 URB4 1 URB5 1 URB6 1 URB7 1 URB8 1 URB9 1 URB10 1 URB11 1
URB12 1 URB13 1 URB14 1 URB15 1 URB16 1 URB17 1
park 16.42hr
END
RUN
TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 8
N
PARAMVAR
NAMCYC
N
hiway 4
park 7.04hr
fedral 1
hiway 1
fedral 1
park 0.66hr
fedral 1
park 14.09hr
END
RUN
TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 9
N
PARAMVAR
NAMCYC
N
hiway 4
park 6.5hr
fedral 1
hiway 4
fedral 1
park 15.04hr
END
RUN
TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 10
N
QUIT
```

```
^Z
%CREATE-I-CREATED, $1A0:[ORCUSER]ELTEST.COM;1 created
$ SUBMIT ELTEST.COM/NOPRINT/QUE=FIFO
  Job 338 entered on queue FIFO
```

(SUBMIT BATCH JOB)

```
$ log

type eltest.log

 $ ON CONTROL_Y THEN $SET NOCONTROL_Y  !Trap for escapes to the $
$ if F$mode() .eqs."BATCH" Then Goto Batch_Exit
$ Batch_Exit:  ! These are only commands executed by everyone.
$
$   Exit
$ SET PROT=(S:REW,O:REWD,G:RE,W:RE)/DEFAULT
$ IF "BATCH".EQS."BATCH" THEN GOTO BATCH
$ BATCH:
$@SIAO:[ORCUSER.STORE]RUNELVEC
$ set noverify
GRC ELECTRIC VEHICLE/BATTERY SIMULATION.  VERSION 8.4  16APR84    -
 SPECIFY DESIRED OUTPUT UNITS - METRIC OR ENGLISH . . .
>
INITIATING BULK READ...DO YOU WANT TO SEE INTRODUCTORY PRINTOUT(Y OR N)?
>
BULK READ COMPLETE-
GEETV1      GEMTDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
DO YOU WANT CARD IMAGES OF SPECIAL DATA PRINTED (Y OR N)?
>
EV2-13/A   BATTDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
DO YOU WANT CARD IMAGES OF SPECIAL DATA PRINTED (Y OR N)?
>
 INPUT CHANGES FOR NEXT RUN-
>
NAME OF DATA PACKAGE...
>
WT 1060 WB 166 CDA 0.555 CRDIAL 0.85
NAMCYC FEDRAL NREGEN 2 VMINRG 5MPH ACLFAC 0.5 ACLRCS 1.5MPH
NAMHYB EV
MDLBAT FRCTUT NAMBAT AL-AIR
MDLMOT ANALYT PKEFF 0.9 0.9 EXPTRQ 0.15 0.15 PEFOMG RPM 10000 10000
PEFPWR KW 20 20
NAMCLC DRCOUP RATIO .282 16 GEAR 1 1 1 1
VELSCD 300 300 300 SHFDWN 300 300 300 EFFCT 0.9 0.9 0.9 0.9
DELT 1 TSTOP 20000
END DATA
>
>
>
>
INPUT NAME OF PARAMETER, INITIAL VALUE, FINAL VALUE, AND NUM STEPS-
>
FEDRAL      SCHDDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
FEDRAL CYCLE. 1372 VALUES READ.
DO YOU WANT A SUMMARY OF THE URBAN SUBSEGMENTS (Y OR N)?
>
INPUT NAME AND NUMBER OF CYCLES. INPUT END WHEN DONE.
FOR 'PARK' AND 'IDLE' CYCLES, INPUT NAME AND PERIOD
>
>
>
>
>
>
 INPUT COMPLETE FOR THIS CASE
```

(ELTEST.LOG)

```
NI-FE1.0   BATTDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
DO YOU WANT CARD IMAGES OF SPECIAL DATA PRINTED (Y OR N)?
>
 VALUE DEFINED FOR UNIT NAME  SCLF  -
NEW DATA HEAD IN TABLES...OVERRIDE, IF NECESSARY
>
>
>
PACC 0
>
WT 1756.86
>
WB 489.0176
>
CDA .6
>
CRDIAL 1
>
PTIRE 38
>
PEFPWR KW 44.27287  44.27287
>
PMXANL 88.54573KW
>
PKEFF .95  .95
>
EFFCD .58
>
CH 3.85854 -.723694 -9.854738-03
>
END
 INPUT COMPLETE FOR THIS CASE
 INPUT A 1-78 CHARACTER TITLE FOR THIS CASE-
>


TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 1
DATE    4-OCT-84
TIME    09:56:19


ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  1 OF THE URBAN SCHEDULE

KEY PARAMETERS (METRIC UNITS)
  ------------VEHICLE-----------  ----------STRATEGY-----------
   WB    WT    CDA   TTIRE PTIRE  ACLFAC  ACLRCS  FBRKS  NREGEN  EFFCM  EFFCFW
   489  1757  0.600  RADIAL 38.0   0.50   -0.67    0.30    2     0.000  0.585

--------------MODELS----------------
DRCOUP  ANALYT  NI-FE1.0    EV

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  2 OF THE URBAN SCHEDULE

PARKING FOR  1.900 HOURS

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  3 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  4 OF THE URBAN SCHEDULE
```

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 5 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 6 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 7 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 8 OF THE URBAN SCHEDULE

PARKING FOR 21.900 HOURS

SCHEDULE	PERIOD	RANGE	AVERAGE SPEED	ROAD ENERGY W/O RGN	ENERGY W RGN	MAX ROAD POWER
	SEC	MI	MI/H	WH/MI		HP
URB1	86373	4.224	0.2	215.5	110.5	50.6

ENERGY AND EFFICIENCY SUMMARY FOR RANGE TRAVELED-

MAJOR SUBSYSTEM LOSSES AND EFFICIENCIES-

	BATT SYS	MTR/CNT	DRVTRN	PWRTRN	BRAKES	MISC
WH/MI	280.0	36.1	31.7	67.8	34.3	44.4
PRCNT(PWRTRN)	413.1	53.3	46.7	100.0	50.6	65.6
PRCNT(OVERALL)	52.1	6.7	5.9	12.6	6.4	8.3
EFFICIENCY	0.527	0.891	0.898	0.803		

COMPONENT LOSS BY DRIVING PHASE(WH/MI AND PERCENT OF OVERALL)-

	TOTAL	ACCEL	CRUISE	COAST	BRAKE	DWELL
OVERALL.WH/MI	537.1					
EFFICIENCY	0.270					
MOTOR	36.1	22.4	2.6	0.0	11.2	0.0
PERCENT	6.7	4.2	0.5	0.0	2.1	0.0
EFFICIENCY	0.891	0.902	0.881	0.000	0.865	0.000
TRANSMISSION	31.7	20.6	2.0	0.0	9.1	0.0
PERCENT	5.9	3.8	0.4	0.0	1.7	0.0
EFFICIENCY	0.898	0.900	0.897	0.000	0.896	0.000
AERO	48.6	19.9	7.8	0.0	20.9	0.0
PERCENT	9.1	3.7	1.5	0.0	3.9	0.0
TIRES	61.9	28.0	7.8	0.0	26.0	0.0
PERCENT	11.5	5.2	1.5	0.0	4.8	0.0
MISCELLAN	44.4	0.1	0.0	0.0	0.1	44.2
PERCENT	8.3	0.0	0.0	0.0	0.0	8.2

BATTERY AND CHARGER

ENERGY OUT WH/MI	ENERGY IN WH/MI	ENERGY LOSS WH/MI	ENERGY LOSS PRCNT	POWER.MX OUT W/LB	POWER.MX IN W/LB	FINAL STATE	BATT EFF	CHARGER LOSS WH/MI	CHARGER LOSS PRCNT	CHARGER EFF
313	55	226	42.1	41.2	16.9	0.000	0.58	54	10.00	0.900

TOTAL RANGE MI	ELECT CONSM AT WALL WH/MI	ELECT CONSM AT WALL WH/MI*TON	ELECT COST (AT 10.0C/KWH) C/MI
101.8	537.2	277.4	5.37
80.9 *			

* - BASED ON LOWEST DEPTH OF DISCHARGE (0.794)WHICH COULD

```
    SUSTAIN THE MAXIMUM POWER DENSITY (  90.9 W/KG).

EQUIVALENT FUEL CONSUMPTION AND ECONOMY (GASOLINE)-

    SOURCE OF        CONSUMPTION      ECONOMY
  PRIMARY ENERGY       LIT/KM     KM/LIT  MI/GAL
    PETROLEUM          0.09847     10.2    23.9
    COAL               0.05693     17.6    41.3

DO YOU WANT THE CAFE VALUE COMPUTED?
>
N


*****************************************************************************

 INPUT CHANGES FOR NEXT RUN-
>
PARAMVAR
INPUT NAME OF PARAMETER, INITIAL VALUE, FINAL VALUE, AND NUM STEPS-
>
NAMCYC
DO YOU WANT A SUMMARY OF THE URBAN SUBSEGMENTS (Y OR N)?
>
N
INPUT NAME AND NUMBER OF CYCLES. INPUT END WHEN DONE.
FOR 'PARK' AND 'IDLE' CYCLES, INPUT NAME AND PERIOD
>
URB1 1 URB2 1 URB3 1 URB4 1 URB5 1 URB6 1
>
PARK 5.01HR
>
URB7 1 URB8 1 URB9 1 URB10 1 URB11 1 URB12 1 URB13 1 URB14 1 URB15 1 URB16 1
>
URB17 1
>
PARK 18.60HR
>
END
>
RUN
 INPUT COMPLETE FOR THIS CASE
 INPUT A 1-78 CHARACTER TITLE FOR THIS CASE-
>


TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 2
DATE     4-OCT-84
TIME   09:57:07


ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  1 OF THE URBAN SCHEDULE

KEY PARAMETERS (METRIC UNITS)
  ------------VEHICLE-----------  -----------STRATEGY-----------
   WB    WT    CDA   TTIRE PTIRE  ACLFAC  ACLRCS  FBRKS  NREGEN   EFFCM  EFFCFW
   489  1757  0.600  RADIAL 38.0   0.50   -0.67   0.30     2     0.000  0.585

--------------MODELS----------------
```

DHCOUP ANALYT NI-FE1.0 EV

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 2 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 3 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 4 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 5 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 6 OF THE URBAN SCHEDULE

PARKING FOR 5.010 HOURS

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 7 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 8 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 9 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 10 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 11 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 12 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 13 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 14 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 15 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 16 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 17 OF THE URBAN SCHEDULE

PARKING FOR 18.600 HOURS

SCHEDULE	PERIOD	RANGE	AVERAGE SPEED	ROAD ENERGY W/O RGN	ROAD ENERGY W RGN	MAX ROAD POWER
	SEC	MI	MI/H	WH/MI	WH/MI	HP
URB1	86367	7.455	0.3	202.3	97.6	50.6

ENERGY AND EFFICIENCY SUMMARY FOR RANGE TRAVELED-

MAJOR SUBSYSTEM LOSSES AND EFFICIENCIES-

	BATT SYS	MTR/CNT	DRVTRN	PWRTRN	BRAKES	MISC
WH/MI	250.1	37.9	30.3	68.2	34.6	25.2
PRCNT(PWRTRN)	366.5	55.6	44.4	100.0	50.7	36.9
PRCNT(OVERALL)	52.6	8.0	6.4	14.3	7.3	5.3
EFFICIENCY	0.528	0.881	0.898	0.793		

COMPONENT LOSS BY DRIVING PHASE(WH/MI AND PERCENT OF OVERALL)-

	TOTAL	ACCEL	CRUISE	COAST	BRAKE	DWELL
OVERALL,WH/MI	475.7					
EFFICIENCY	0.278					
MOTOR	37.9	23.7	2.3	0.0	11.9	0.0
PERCENT	8.0	5.0	0.5	0.0	2.5	0.0
EFFICIENCY	0.881	0.893	0.871	0.000	0.850	0.000

```
TRANSMISSION      30.3      19.8       1.7      0.0       8.8      0.0
 PERCENT           6.4       4.2       0.4      0.0       1.9      0.0
 EFFICIENCY      0.898     0.899     0.895    0.000     0.895    0.000
AERO              36.0      14.7       5.6      0.0      15.7      0.0
 PERCENT           7.6       3.1       1.2      0.0       3.3      0.0
TIRES             61.6      27.6       7.6      0.0      26.4      0.0
 PERCENT          12.9       5.8       1.6      0.0       5.6      0.0
MISCELLAN         25.2       0.2       0.0      0.0       0.1     24.9
 PERCENT           5.3       0.0       0.0      0.0       0.0      5.2

----------------------BATTERY AND CHARGER--------------------
-------ENERGY------     POWER,MX   FINAL  BATT   -----CHARGER-----
OUT   IN    LOSS      OUT   IN    STATE  EFF       LOSS      EFF
  WH/MI  WH/MI PRCNT    W/LB                     WH/MI PRCNT
280   54  203  42.6   41.2  16.9  0.000  0.58    48 10.00  0.900



    TOTAL      ELECT CONSM      ELECT COST
    RANGE        AT WALL      (AT 10.0C/KWH)
     MI      WH/MI  WH/MI*TON      C/MI

    119.9    475.8    245.7         4.76
     95.2 *

* - BASED ON LOWEST DEPTH OF DISCHARGE ( 0.794)WHICH COULD
    SUSTAIN THE MAXIMUM POWER DENSITY (  90.9 W/KG).

EQUIVALENT FUEL CONSUMPTION AND ECONOMY (GASOLINE)-

   SOURCE OF       CONSUMPTION     ECONOMY
 PRIMARY ENERGY      LIT/KM     KM/LIT  MI/GAL
   PETROLEUM         0.08642      11.6    27.2
   COAL              0.04996      20.0    47.1

DO YOU WANT THE CAFE VALUE COMPUTED?
>
N


*************************************************************************

 INPUT CHANGES FOR NEXT RUN-
>
PARAMVAR
INPUT NAME OF PARAMETER, INITIAL VALUE, FINAL VALUE, AND NUM STEPS-
>
NAMCYC
DO YOU WANT A SUMMARY OF THE URBAN SUBSEGMENTS (Y OR N)?
>
N
INPUT NAME AND NUMBER OF CYCLES. INPUT END WHEN DONE.
FOR 'PARK' AND 'IDLE' CYCLES, INPUT NAME AND PERIOD
>
URB1 1
>
PARK 5.16HR
>
URB2 1 URB3 1 URB4 1 URB5 1 URB6 1
```

```
>
PARK 0.75HR
>
URB7 1 URB8 1 URB9 1 URB10 1 URB11 1 URB12 1 URB13 1 URB14 1 URB15 1 URB16 1
>
URB17 1
>
PARK 2.77HR
>
URB1 1 URB2 1 URB3 1 URB4 1 URB5 1 URB6 1
>
URB7 1 URB8 1 URB9 1
>
PARK 14.73HR
>
END
>
RUN
 INPUT COMPLETE FOR THIS CASE
 INPUT A 1-78 CHARACTER TITLE FOR THIS CASE-
>


TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 3
DATE     4-OCT-84
TIME    09:58:02

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  1 OF THE URBAN SCHEDULE

KEY PARAMETERS (METRIC UNITS)
  ------------VEHICLE-----------  ----------STRATEGY-----------
   WB    WT    CDA    TTIRE PTIRE  ACLFAC  ACLRCS  FBRKS  NREGEN  EFFCM  EFFCFW
   489  1757  0.600  RADIAL 38.0   0.50   -0.67    0.30    2     0.000  0.585

--------------MODELS---------------
DRCOUP  ANALYT  NI-FE1.0    EV

PARKING FOR  5.160 HOURS

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  2 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  3 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  4 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  5 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  6 OF THE URBAN SCHEDULE

PARKING FOR  0.750 HOURS

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  7 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  8 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  9 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT 10 OF THE URBAN SCHEDULE
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ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 11 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 12 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 13 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 14 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 15 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 16 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 17 OF THE URBAN SCHEDULE

PARKING FOR 2.770 HOURS

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 1 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 2 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 3 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 4 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 5 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 6 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 7 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 8 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 9 OF THE URBAN SCHEDULE

PARKING FOR 14.730 HOURS

SCHEDULE	PERIOD	RANGE	AVERAGE SPEED	ROAD ENERGY W/O RGN	ROAD ENERGY W RGN	MAX ROAD POWER
	SEC	MI	MI/H	WH/MI	WH/MI	HP
URB1	86413	12.002	0.5	208.4	101.6	50.6

ENERGY AND EFFICIENCY SUMMARY FOR RANGE TRAVELED-

MAJOR SUBSYSTEM LOSSES AND EFFICIENCIES-

	BATT SYS	MTR/CNT	DRVTRN	PWRTRN	BRAKES	MISC
WH/MI	247.5	37.9	31.1	69.0	35.2	15.6
PRCNT(PWRTRN)	358.8	54.9	45.1	100.0	51.1	22.7
PRCNT(OVERALL)	52.8	8.1	6.6	14.7	7.5	3.3
EFFICIENCY	0.528	0.884	0.898	0.796		

COMPONENT LOSS BY DRIVING PHASE(WH/MI AND PERCENT OF OVERALL)-

	TOTAL	ACCEL	CRUISE	COAST	BRAKE	DWELL
OVERALL,WH/MI	468.9					
EFFICIENCY	0.292					
MOTOR	37.9	23.6	2.4	0.0	11.8	0.0
PERCENT	8.1	5.0	0.5	0.0	2.5	0.0
EFFICIENCY	0.884	0.895	0.875	0.000	0.854	0.000
TRANSMISSION	31.1	20.3	1.8	0.0	9.0	0.0

PERCENT	6.6	4.3	0.4	0.0	1.9	0.0
EFFICIENCY	0.898	0.899	0.896	0.000	0.895	0.000
AERO	39.9	16.4	6.2	0.0	17.3	0.0
PERCENT	8.5	3.5	1.3	0.0	3.7	0.0
TIRES	61.7	27.8	7.5	0.0	26.3	0.0
PERCENT	13.2	5.9	1.6	0.0	5.6	0.0
MISCELLAN	15.6	0.2	0.0	0.0	0.1	15.3
PERCENT	3.3	0.0	0.0	0.0	0.0	3.3

----------------------BATTERY AND CHARGER--------------------

-------ENERGY------				POWER.MX		FINAL	BATT	-----CHARGER-----		
OUT	IN	LOSS		OUT	IN	STATE	EFF	LOSS		EFF
WH/MI	WH/MI	PRCNT		W/LB				WH/MI	PRCNT	
277	56	201	42.8	41.2	16.9	0.000	0.58	47	10.00	0.900

TOTAL RANGE MI	ELECT CONSM AT WALL WH/MI	WH/MI*TON	ELECT COST (AT 10.0C/KWH) C/MI
118.7	469.0	242.2	4.69
94.3 *			

* - BASED ON LOWEST DEPTH OF DISCHARGE (0.794)WHICH COULD
SUSTAIN THE MAXIMUM POWER DENSITY (90.9 W/KG).

EQUIVALENT FUEL CONSUMPTION AND ECONOMY (GASOLINE)-

SOURCE OF PRIMARY ENERGY	CONSUMPTION LIT/KM	ECONOMY KM/LIT	MI/GAL
PETROLEUM	0.08483	11.8	27.7
COAL	0.04905	20.4	48.0

DO YOU WANT THE CAFE VALUE COMPUTED?
>
N

****

INPUT CHANGES FOR NEXT RUN-
>
PARAMVAR
INPUT NAME OF PARAMETER, INITIAL VALUE, FINAL VALUE, AND NUM STEPS-
>
NAMCYC
DO YOU WANT A SUMMARY OF THE URBAN SUBSEGMENTS (Y OR N)?
>
N
INPUT NAME AND NUMBER OF CYCLES. INPUT END WHEN DONE.
FOR 'PARK' AND 'IDLE' CYCLES, INPUT NAME AND PERIOD
>
FEDHAL 1
>
PARK 0.95HR
>
URB2 1
>

```
PARK 3.44HR
>
FEDRAL 1
>
PARK 18.79HR
>
END
>
RUN
 INPUT COMPLETE FOR THIS CASE
 INPUT A 1-78 CHARACTER TITLE FOR THIS CASE-
>


TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 4
DATE    4-OCT-84
TIME   10:04:02


ITERATION NUMBER  1 NAMCYC = FEDRAL

KEY PARAMETERS (METRIC UNITS)
  -------------VEHICLE----------- ----------STRATEGY----------
   WB    WT    CDA    TTIRE PTIRE  ACLFAC  ACLRCS  FBRKS  NREGEN   EFFCM  EFFCFW
   489  1757  0.600  RADIAL 38.0   0.50   -0.67    0.30    2      0.000  0.585

--------------MODELS----------------
DRCOUP  ANALYT  NI-FE1.0    EV

PARKING FOR  0.930 HOURS

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  2 OF THE URBAN SCHEDULE

PARKING FOR  3.440 HOURS

ITERATION NUMBER  1 NAMCYC = FEDRAL

PARKING FOR 18.790 HOURS

SCHEDULE  PERIOD  RANGE  AVERAGE  ROAD  ENERGY  MAX ROAD
                          SPEED  W/O RGN  W RGN  POWER
           SEC      MI    MI/H       WH/MI         HP
 FEDRAL  86373  16.862    0.7    202.5   102.5    50.6

ENERGY AND EFFICIENCY SUMMARY FOR RANGE TRAVELED-
----------------------------------------------------------------------
 MAJOR SUBSYSTEM LOSSES AND EFFICIENCIES-
                    BATT SYS   MTR/CNT   DRVTRN    PWRTRN    BRAKES     MISC
  WH/MI               237.1      36.7     30.0      66.7      33.0      11.1
   PRCNT(PWRTRN)      355.3      55.0     45.0     100.0      49.4      16.7
   PRCNT(OVERALL)      52.6       8.1      6.7      14.8       7.3       2.5
  EFFICIENCY          0.528     0.884    0.898     0.796
----------------------------------------------------------------------

 COMPONENT LOSS BY DRIVING PHASE(WH/MI AND PERCENT OF OVERALL)-
                    TOTAL     ACCEL     CRUISE    COAST     BRAKE     DWELL
 OVERALL,WH/MI      450.4
  EFFICIENCY        0.301
 MOTOR               36.7      22.7       2.4       0.0      11.5       0.0
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 PERCENT            8.1       5.1       0.5       0.0       2.6       0.0
 EFFICIENCY       0.884     0.896     0.875     0.000     0.852     0.000
TRANSMISSION       30.0      19.6       1.8       0.0       8.6       0.0
 PERCENT            6.7       4.4       0.4       0.0       1.9       0.0
 EFFICIENCY       0.898     0.899     0.896     0.000     0.895     0.000
AERO               40.7      16.5       6.4       0.0      17.8       0.0
 PERCENT            9.0       3.7       1.4       0.0       4.0       0.0
TIRES              61.7      27.3       7.7       0.0      26.7       0.0
 PERCENT           13.7       6.1       1.7       0.0       5.9       0.0
MISCELLAN          11.1       0.1       0.0       0.0       0.1      10.8
 PERCENT            2.5       0.0       0.0       0.0       0.0       2.4

----------------------BATTERY AND CHARGER---------------------
-------ENERGY------     POWER,MX   FINAL  BATT   -----CHARGER-----
OUT   IN    LOSS        OUT   IN   STATE  EFF       LOSS      EFF
  WH/MI  WH/MI PRCNT      W/LB                   WH/MI PRCNT
265   52  192  42.6    41.2  16.9  0.000  0.58    45 10.00  0.900


   TOTAL      ELECT CONSM      ELECT COST
   RANGE        AT WALL      (AT 10.0C/KWH)
    MI      WH/MI  WH/MI*TON      C/MI

   123.1    450.5    232.6         4.50
    97.7 *

* - BASED ON LOWEST DEPTH OF DISCHARGE ( 0.794)WHICH COULD
    SUSTAIN THE MAXIMUM POWER DENSITY (   90.9 W/KG).

EQUIVALENT FUEL CONSUMPTION AND ECONOMY (GASOLINE)-

   SOURCE OF       CONSUMPTION     ECONOMY
 PRIMARY ENERGY      LIT/KM     KM/LIT  MI/GAL
   PETROLEUM         0.08171     12.2    28.8
   COAL              0.04724     21.2    49.8

DO YOU WANT THE CAFE VALUE COMPUTED?
>
N

*****************************************************************************

 INPUT CHANGES FOR NEXT RUN-
>
PARAMVAR
INPUT NAME OF PARAMETER, INITIAL VALUE, FINAL VALUE, AND NUM STEPS-
>
NAMCYC
DO YOU WANT A SUMMARY OF THE URBAN SUBSEGMENTS (Y OR N)?
>
N
INPUT NAME AND NUMBER OF CYCLES. INPUT END WHEN DONE.
FOR 'PARK' AND 'IDLE' CYCLES, INPUT NAME AND PERIOD
>
URB1 1 URB2 1 URB3 1 URB4 1 URB5 1 URB6 1
>
PARK 7.15HR
```

```
>
URB7 1 URB8 1 URB9 1 URB10 1 URB11 1 URB12 1 URB13 1 URB14 1 URB15 1 URB16 1
>
URB17 1
>
PARK 1.56HR
>
FEURAL 1
>
PARK 6.87HR
>
FEDRAL 1
>
PARK 7.28HR
>
END
>
RUN
 INPUT COMPLETE FOR THIS CASE
 INPUT A 1-78 CHARACTER TITLE FOR THIS CASE-
>


TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 5
DATE    4-OCT-84
TIME    10:06:08

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  1 OF THE URBAN SCHEDULE

KEY PARAMETERS (METRIC UNITS)
   ------------VEHICLE-----------  ----------STRATEGY-----------
    WB    WT    CDA   TTIRE PTIRE  ACLFAC  ACLRCS  FBRKS  NREGEN  EFFCM  EFFCFW
   489  1757  0.600  RADIAL 38.0    0.50   -0.67    0.30     2    0.000  0.585

--------------MODELS----------------
DRCOUP  ANALYT  NI-FE1.0    EV

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  2 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  3 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  4 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  5 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  6 OF THE URBAN SCHEDULE

PARKING FOR  7.150 HOURS

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  7 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  8 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  9 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT 10 OF THE URBAN SCHEDULE

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT 11 OF THE URBAN SCHEDULE
```

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 12 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 13 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 14 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 15 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 16 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 17 OF THE URBAN SCHEDULE

PARKING FOR 1.560 HOURS

ITERATION NUMBER 1 NAMCYC = FEDRAL

PARKING FOR 6.870 HOURS

ITERATION NUMBER 1 NAMCYC = FEDRAL

PARKING FOR 7.280 HOURS

SCHEDULE	PERIOD	RANGE	AVERAGE SPEED	ROAD ENERGY W/O RGN	ROAD ENERGY W RGN	MAX ROAD POWER
	SEC	MI	MI/H	WH/MI	WH/MI	HP
URB1	86409	22.355	0.9	202.3	97.6	50.6

ENERGY AND EFFICIENCY SUMMARY FOR RANGE TRAVELED-

MAJOR SUBSYSTEM LOSSES AND EFFICIENCIES-

	BATT SYS	MTR/CNT	DRVTRN	PWRTRN	BRAKES	MISC
WH/MI	234.8	37.9	30.3	68.3	34.6	8.4
PRCNT(PWRTRN)	344.0	55.6	44.4	100.0	50.7	12.3
PRCNT(OVERALL)	52.9	8.6	6.8	15.4	7.8	1.9
EFFICIENCY	0.528	0.881	0.898	0.793		

COMPONENT LOSS BY DRIVING PHASE(WH/MI AND PERCENT OF OVERALL)-

	TOTAL	ACCEL	CRUISE	COAST	BRAKE	DWELL
OVERALL,WH/MI	443.7					
EFFICIENCY	0.298					
MOTOR	37.9	23.7	2.3	0.0	11.9	0.0
PERCENT	8.6	5.3	0.5	0.0	2.7	0.0
EFFICIENCY	0.881	0.893	0.871	0.000	0.850	0.000
TRANSMISSION	30.3	19.8	1.7	0.0	8.8	0.0
PERCENT	6.8	4.5	0.4	0.0	2.0	0.0
EFFICIENCY	0.898	0.899	0.895	0.000	0.895	0.000
AERO	36.0	14.8	5.6	0.0	15.7	0.0
PERCENT	8.1	3.3	1.3	0.0	3.5	0.0
TIRES	61.6	27.6	7.6	0.0	26.4	0.0
PERCENT	13.9	6.2	1.7	0.0	6.0	0.0
MISCELLAN	8.4	0.2	0.0	0.0	0.1	8.1
PERCENT	1.9	0.0	0.0	0.0	0.0	1.8

BATTERY AND CHARGER

ENERGY OUT WH/MI	ENERGY IN WH/MI	ENERGY LOSS WH/MI	ENERGY LOSS PRCNT	POWER,MX OUT W/LB	POWER,MX IN W/LB	FINAL STATE	BATT EFF	CHARGER LOSS WH/MI	CHARGER LOSS PRCNT	CHARGER EFF
263	54	190	42.9	41.2	16.9	0.000	0.58	44	10.00	0.900

```
    TOTAL        ELECT CONSM        ELECT COST
    RANGE          AT WALL        (AT 10.0C/KWH)
     MI        WH/MI   WH/MI*TON       C/MI

    127.1      443.8     229.2          4.44
    100.9 *

* - BASED ON LOWEST DEPTH OF DISCHARGE ( 0.794)WHICH COULD
    SUSTAIN THE MAXIMUM POWER DENSITY (  90.9 W/KG).

EQUIVALENT FUEL CONSUMPTION AND ECONOMY (GASOLINE)-

   SOURCE OF         CONSUMPTION       ECONOMY
 PRIMARY ENERGY        LIT/KM      KM/LIT   MI/GAL
   PETROLEUM           0.08002      12.5     29.4
   COAL                0.04627      21.6     50.8

DO YOU WANT THE CAFE VALUE COMPUTED?
>
N


*******************************************************************************

 INPUT CHANGES FOR NEXT RUN-
>
PARAMVAR
INPUT NAME OF PARAMETER, INITIAL VALUE, FINAL VALUE, AND NUM STEPS-
>
NAMCYC
DO YOU WANT A SUMMARY OF THE URBAN SUBSEGMENTS (Y OR N)?
>
N
INPUT NAME AND NUMBER OF CYCLES. INPUT END WHEN DONE.
FOR 'PARK' AND 'IDLE' CYCLES, INPUT NAME AND PERIOD
>
FEDRAL 2
>
PARK 1.04HR
>
URB1 1 URB2 1 URB3 1 URB4 1 URB5 1 URB6 1
>
URB7 1 URB8 1 URB9 1
>
PARK 0.87HR
>
URB1 1 URB2 1
>
PARK 6.83HR
>
URB3 1 URB4 1 URB5 1 URB6 1 URB7 1 URB8 1 URB9 1 URB10 1 URB11 1
>
URB12 1 URB13 1 URB14 1 URB15 1 URB16 1 URB17 1
>
PARK 1.63HR
>
```

```
FEDRAL 1
>
PARK 11.89HR
>
END
>
RUN
 INPUT COMPLETE FOR THIS CASE
 INPUT A 1-78 CHARACTER TITLE FOR THIS CASE-
>


TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 6
DATE     4-OCT-84
TIME    10:18:37


ITERATION NUMBER   1 NAMCYC = FEDRAL

KEY PARAMETERS (METRIC UNITS)
  ------------VEHICLE----------  ----------STRATEGY-----------
    WB    WT    CDA   TTIRE PTIRE  ACLFAC  ACLRCS  FBRKS  NREGEN  EFFCM  EFFCFW
   489  1757  0.600  RADIAL 38.0   0.50   -0.67    0.30    2     0.000  0.585

--------------MODELS----------------
DRCOUP  ANALYT  NI-FE1.0    EV

ITERATION NUMBER   2 NAMCYC = FEDRAL

PARKING FOR  1.040 HOURS

ITERATION NUMBER   1 CONSISTING OF SUBSEGMENT   1 OF THE URBAN SCHEDULE

ITERATION NUMBER   1 CONSISTING OF SUBSEGMENT   2 OF THE URBAN SCHEDULE

ITERATION NUMBER   1 CONSISTING OF SUBSEGMENT   3 OF THE URBAN SCHEDULE

ITERATION NUMBER   1 CONSISTING OF SUBSEGMENT   4 OF THE URBAN SCHEDULE

ITERATION NUMBER   1 CONSISTING OF SUBSEGMENT   5 OF THE URBAN SCHEDULE

ITERATION NUMBER   1 CONSISTING OF SUBSEGMENT   6 OF THE URBAN SCHEDULE

ITERATION NUMBER   1 CONSISTING OF SUBSEGMENT   7 OF THE URBAN SCHEDULE

ITERATION NUMBER   1 CONSISTING OF SUBSEGMENT   8 OF THE URBAN SCHEDULE

ITERATION NUMBER   1 CONSISTING OF SUBSEGMENT   9 OF THE URBAN SCHEDULE

PARKING FOR  0.870 HOURS

ITERATION NUMBER   1 CONSISTING OF SUBSEGMENT   1 OF THE URBAN SCHEDULE

ITERATION NUMBER   1 CONSISTING OF SUBSEGMENT   2 OF THE URBAN SCHEDULE

PARKING FOR  6.830 HOURS

ITERATION NUMBER   1 CONSISTING OF SUBSEGMENT   3 OF THE URBAN SCHEDULE
```

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 4 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 5 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 6 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 7 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 8 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 9 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 10 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 11 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 12 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 13 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 14 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 15 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 16 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 17 OF THE URBAN SCHEDULE

PARKING FOR 1.630 HOURS

ITERATION NUMBER 1 NAMCYC = FEDRAL

PARKING FOR 11.890 HOURS

SCHEDULE	PERIOD	RANGE	AVERAGE SPEED	ROAD ENERGY W/O RGN	ROAD ENERGY W RGN	MAX ROAD POWER
	SEC	MI	MI/H	WH/MI	WH/MI	HP
FEDRAL	86385	34.353	1.4	204.5	99.0	50.6

ENERGY AND EFFICIENCY SUMMARY FOR RANGE TRAVELED-

MAJOR SUBSYSTEM LOSSES AND EFFICIENCIES-

	BATT SYS	MTR/CNT	DRVTRN	PWRTRN	BRAKES	MISC
WH/MI	234.3	37.9	30.6	68.5	34.8	5.5
PRCNT(PWRTRN)	341.9	55.3	44.7	100.0	50.8	8.0
PRCNT(OVERALL)	53.0	8.6	6.9	15.5	7.9	1.2
EFFICIENCY	0.528	0.882	0.898	0.794		

COMPONENT LOSS BY DRIVING PHASE(WH/MI AND PERCENT OF OVERALL)-

	TOTAL	ACCEL	CRUISE	COAST	BRAKE	DWELL
OVERALL,WH/MI	442.1					
EFFICIENCY	0.303					
MOTOR	37.9	23.7	2.4	0.0	11.9	0.0
PERCENT	8.6	5.4	0.5	0.0	2.7	0.0
EFFICIENCY	0.882	0.894	0.873	0.000	0.851	0.000
TRANSMISSION	30.6	20.0	1.7	0.0	8.9	0.0
PERCENT	6.9	4.5	0.4	0.0	2.0	0.0
EFFICIENCY	0.898	0.899	0.896	0.000	0.895	0.000
AERO	37.4	15.3	5.8	0.0	16.2	0.0

PERCENT	8.5	3.5	1.3	0.0	3.7	0.0
TIRES	61.6	27.7	7.6	0.0	26.4	0.0
PERCENT	13.9	6.3	1.7	0.0	6.0	0.0
MISCELLAN	5.5	0.2	0.0	0.0	0.1	5.1
PERCENT	1.2	0.0	0.0	0.0	0.0	1.2

```
-----------------------BATTERY AND CHARGER---------------------
-------ENERGY------      POWER,MX   FINAL  BATT   -----CHARGER-----
OUT   IN    LOSS         OUT    IN   STATE  EFF       LOSS       EFF
  WH/MI  WH/MI PRCNT       W/LB                   WH/MI PRCNT
262   55  190  43.0   41.2  16.9  0.000  0.58    44 10.00  0.900
```

```
   TOTAL       ELECT CONSM        ELECT COST
   RANGE         AT WALL       (AT 10.0C/KWH)
    MI        WH/MI  WH/MI*TON      C/MI

   126.5     442.2    228.3          4.42
   100.4 *
```

* - BASED ON LOWEST DEPTH OF DISCHARGE (0.794)WHICH COULD
SUSTAIN THE MAXIMUM POWER DENSITY (90.9 W/KG).

EQUIVALENT FUEL CONSUMPTION AND ECONOMY (GASOLINE)-

SOURCE OF PRIMARY ENERGY	CONSUMPTION LIT/KM	ECONOMY KM/LIT	MI/GAL
PETROLEUM	0.07962	12.6	29.5
COAL	0.04603	21.7	51.1

```
DO YOU WANT THE CAFE VALUE COMPUTED?
>
N

******************************************************************************

 INPUT CHANGES FOR NEXT RUN-
>
PARAMVAR
INPUT NAME OF PARAMETER, INITIAL VALUE, FINAL VALUE, AND NUM STEPS-
>
NAMCYC
DO YOU WANT A SUMMARY OF THE URBAN SUBSEGMENTS (Y OR N)?
>
N
INPUT NAME AND NUMBER OF CYCLES. INPUT END WHEN DONE.
FOR 'PARK' AND 'IDLE' CYCLES, INPUT NAME AND PERIOD
>
FEDRAL 2
>
PARK 4.57HR
>
URB1 1
>
PARK 0.60HR
>
FEDRAL 2
```

```
>
PARK 2.57HR
>
FEDRAL 1
>
PARK 1.38HR
>
FEDRAL 1
>
PARK 12.55HR
>
END
>
RUN
 INPUT COMPLETE FOR THIS CASE
 INPUT A 1-78 CHARACTER TITLE FOR THIS CASE-
>
```

```
TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 7
DATE     4-OCT-84
TIME     11:44:40

ITERATION NUMBER  1 NAMCYC = FEDRAL

KEY PARAMETERS (METRIC UNITS)
  -----------VEHICLE-----------  ----------STRATEGY-----------
   WB    WT    CDA    TTIRE  PTIRE  ACLFAC  ACLRCS  FBRKS  NREGEN  EFFCM  EFFCFW
   489  1757  0.600  RADIAL 38.0   0.50   -0.67    0.30     2     0.000  0.585

-------------MODELS----------------
DRCOUP  ANALYT  NI-FE1.0    EV

ITERATION NUMBER  2 NAMCYC = FEDRAL

PARKING FOR  4.570 HOURS

ITERATION NUMBER  1 CONSISTING OF SUBSEGMENT  1 OF THE URBAN SCHEDULE

PARKING FOR  0.600 HOURS

ITERATION NUMBER  1 NAMCYC = FEDRAL

ITERATION NUMBER  2 NAMCYC = FEDRAL

PARKING FOR  2.570 HOURS

ITERATION NUMBER  1 NAMCYC = FEDRAL

PARKING FOR  1.380 HOURS

ITERATION NUMBER  1 NAMCYC = FEDRAL

PARKING FOR 12.550 HOURS

SCHEDULE  PERIOD  RANGE  AVERAGE  ROAD  ENERGY  MAX ROAD
                          SPEED  W/O RGN  W RGN  POWER
           SEC      MI     MI/H       WH/MI          HP
```

FEDRAL 86401 45.376 1.9 202.2 97.4 50.6

ENERGY AND EFFICIENCY SUMMARY FOR RANGE TRAVELED-

MAJOR SUBSYSTEM LOSSES AND EFFICIENCIES-

	BATT SYS	MTR/CNT	DRVTRN	PWRTRN	BRAKES	MISC
WH/MI	230.8	37.9	30.3	68.2	34.6	4.1
PRCNT(PWRTRN)	338.2	55.6	44.4	100.0	50.7	6.1
PRCNT(OVERALL)	53.0	8.7	7.0	15.7	8.0	1.0
EFFICIENCY	0.528	0.881	0.898	0.793		

COMPONENT LOSS BY DRIVING PHASE(WH/MI AND PERCENT OF OVERALL)-

	TOTAL	ACCEL	CRUISE	COAST	BRAKE	DWELL
OVERALL,WH/MI	435.2					
EFFICIENCY	0.303					
MOTOR	37.9	23.7	2.3	0.0	11.9	0.0
PERCENT	8.7	5.5	0.5	0.0	2.7	0.0
EFFICIENCY	0.881	0.893	0.871	0.000	0.850	0.000
TRANSMISSION	30.3	19.9	1.7	0.0	8.8	0.0
PERCENT	7.0	4.6	0.4	0.0	2.0	0.0
EFFICIENCY	0.898	0.899	0.895	0.000	0.895	0.000
AERO	35.8	14.7	5.5	0.0	15.6	0.0
PERCENT	8.2	3.4	1.3	0.0	3.6	0.0
TIRES	61.6	27.7	7.5	0.0	26.4	0.0
PERCENT	14.2	6.4	1.7	0.0	6.1	0.0
MISCELLAN	4.1	0.2	0.0	0.0	0.1	3.8
PERCENT	1.0	0.0	0.0	0.0	0.0	0.9

---------------------BATTERY AND CHARGER--------------------

ENERGY				POWER,MX		FINAL	BATT	CHARGER		
OUT	IN	LOSS		OUT	IN	STATE	EFF	LOSS		EFF
WH/MI	WH/MI		PRCNT	W/LB				WH/MI	PRCNT	
259	54	187	43.0	41.2	16.9	0.000	0.58	44	10.00	0.900

TOTAL RANGE MI	ELECT CONSM AT WALL WH/MI	WH/MI*TON	ELECT COST (AT 10.0C/KWH) C/MI
129.4	435.3	224.8	4.35
102.7 *			

* - BASED ON LOWEST DEPTH OF DISCHARGE (0.794)WHICH COULD
SUSTAIN THE MAXIMUM POWER DENSITY (90.9 W/KG).

EQUIVALENT FUEL CONSUMPTION AND ECONOMY (GASOLINE)-

SOURCE OF PRIMARY ENERGY	CONSUMPTION LIT/KM	ECONOMY KM/LIT	MI/GAL
PETROLEUM	0.07831	12.8	30.0
COAL	0.04528	22.1	51.9

DO YOU WANT THE CAFE VALUE COMPUTED?
>
N

```
*****************************************************************************

 INPUT CHANGES FOR NEXT RUN-
>
PARAMVAR
INPUT NAME OF PARAMETER, INITIAL VALUE, FINAL VALUE, AND NUM STEPS-
>
NAMCYC
DO YOU WANT A SUMMARY OF THE URBAN SUBSEGMENTS (Y OR N)?
>
N
INPUT NAME AND NUMBER OF CYCLES. INPUT END WHEN DONE.
FOR 'PARK' AND 'IDLE' CYCLES, INPUT NAME AND PERIOD
>
FEDRAL 2
>
PARK 0.62HR
>
FEDRAL 2
>
PARK 0.15HR
>
FEDRAL 2
>
PARK 3.73HR
>
URB1 1 URB2 1
>
PARK 0.216HR
>
URB3 1 URB4 1 URB5 1 URB6 1 URB7 1 URB8 1 URB9 1 URB10 1 URB11 1
>
URB12 1 URB13 1 URB14 1 URB15 1 URB16 1 URB17 1
>
PARK 16.42HR
>
END
>
RUN
 INPUT COMPLETE FOR THIS CASE
 INPUT A 1-78 CHARACTER TITLE FOR THIS CASE-
>


TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 8
DATE    4-OCT-84
TIME    11:56:12

ITERATION NUMBER  1 NAMCYC = FEDRAL

KEY PARAMETERS (METRIC UNITS)
  ------------VEHICLE-----------  ----------STRATEGY-----------
   WB    WT    CDA   TTIRE PTIRE  ACLFAC  ACLRCS  FBRKS  NREGEN  EFFCM  EFFCFW
   489  1757  0.600  RADIAL 38.0   0.50   -0.67    0.30    2     0.000  0.585

-------------MODELS---------------
DRCOUP  ANALYT  NI-FE1.0    EV
```

ITERATION NUMBER 2 NAMCYC = FEDRAL

PARKING FOR 0.820 HOURS

ITERATION NUMBER 1 NAMCYC = FEDRAL

ITERATION NUMBER 2 NAMCYC = FEDRAL

PARKING FOR 0.150 HOURS

ITERATION NUMBER 1 NAMCYC = FEDRAL

ITERATION NUMBER 2 NAMCYC = FEDRAL

PARKING FOR 3.730 HOURS

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 1 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 2 OF THE URBAN SCHEDULE

PARKING FOR 0.216 HOURS

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 3 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 4 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 5 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 6 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 7 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 8 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 9 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 10 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 11 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 12 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 13 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 14 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 15 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 16 OF THE URBAN SCHEDULE

ITERATION NUMBER 1 CONSISTING OF SUBSEGMENT 17 OF THE URBAN SCHEDULE

PARKING FOR 16.420 HOURS

SCHEDULE	PERIOD	RANGE	AVERAGE SPEED	ROAD ENERGY W/O RGN	W RGN	MAX ROAD POWER
	SEC	MI	MI/H	WH/MI		HP
FEDRAL	86406	52.157	2.2	202.3	97.6	50.4

ENERGY AND EFFICIENCY SUMMARY FOR RANGE TRAVELED-

MAJOR SUBSYSTEM LOSSES AND EFFICIENCIES-

	BATT SYS	MTR/CNT	DRVTRN	PWRTRN	BRAKES	MISC
WH/MI	230.5	37.9	30.3	68.3	34.6	3.6
PRCNT(PWRTRN)	337.5	55.6	44.4	100.0	50.7	5.3
PRCNT(OVERALL)	53.0	8.7	7.0	15.7	8.0	0.8
EFFICIENCY	0.528	0.881	0.898	0.793		

COMPONENT LOSS BY DRIVING PHASE(WH/MI AND PERCENT OF OVERALL)-

	TOTAL	ACCEL	CRUISE	COAST	BRAKE	DWELL
OVERALL,WH/MI	434.5					
EFFICIENCY	0.304					
MOTOR	37.9	23.7	2.3	0.0	11.9	0.0
PERCENT	8.7	5.5	0.5	0.0	2.7	0.0
EFFICIENCY	0.881	0.893	0.871	0.000	0.850	0.000
TRANSMISSION	30.3	19.8	1.7	0.0	8.8	0.0
PERCENT	7.0	4.6	0.4	0.0	2.0	0.0
EFFICIENCY	0.898	0.899	0.895	0.000	0.895	0.000
AERO	36.0	14.8	5.6	0.0	15.7	0.0
PERCENT	8.3	3.4	1.3	0.0	3.6	0.0
TIRES	61.6	27.6	7.6	0.0	26.5	0.0
PERCENT	14.2	6.3	1.7	0.0	6.1	0.0
MISCELLAN	3.6	0.2	0.0	0.0	0.1	3.3
PERCENT	0.8	0.0	0.0	0.0	0.0	0.8

---------------------BATTERY AND CHARGER--------------------

-------ENERGY------				POWER,MX		FINAL	BATT	-----CHARGER-----		
OUT	IN	LOSS		OUT	IN	STATE	EFF	LOSS		EFF
WH/MI	WH/MI	PRCNT		W/LB				WH/MI	PRCNT	
258	54	187	43.0	41.2	16.9	0.000	0.58	43	10.00	0.900

TOTAL RANGE MI	ELECT CONSM AT WALL WH/MI	WH/MI*TON	ELECT COST (AT 10.0C/KWH) C/MI
129.4	434.7	224.5	4.35
102.7 *			

* - BASED ON LOWEST DEPTH OF DISCHARGE (0.794)WHICH COULD SUSTAIN THE MAXIMUM POWER DENSITY (90.9 W/KG).

EQUIVALENT FUEL CONSUMPTION AND ECONOMY (GASOLINE)-

SOURCE OF PRIMARY ENERGY	CONSUMPTION LIT/KM	ECONOMY KM/LIT	MI/GAL
PETROLEUM	0.07819	12.8	30.1
COAL	0.04521	22.1	52.0

DO YOU WANT THE CAFE VALUE COMPUTED?
>
N

****

INPUT CHANGES FOR NEXT RUN-

```
>
PARAMVAR
INPUT NAME OF PARAMETER, INITIAL VALUE, FINAL VALUE, AND NUM STEPS-
>
NAMCYC
DO YOU WANT A SUMMARY OF THE URBAN SUBSEGMENTS (Y OR N)?
>
N
INPUT NAME AND NUMBER OF CYCLES. INPUT END WHEN DONE.
FOR 'PARK' AND 'IDLE' CYCLES, INPUT NAME AND PERIOD
>
HIWAY 4
>
PARK 7.04HR
>
FEDRAL 1
>
HIWAY 1
>
FEDRAL 1
>
PARK 0.66HR
>
FEDRAL 1
>
PARK 14.09HR
>
END
>
RUN
 INPUT COMPLETE FOR THIS CASE
 INPUT A 1-78 CHARACTER TITLE FOR THIS CASE-
>


TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 9
DATE    4-OCT-84
TIME   12:02:45


ITERATION NUMBER  1 NAMCYC = HIWAY
HIWAY      SCHDDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
HIWAY  CYCLE.  766 VALUES READ.

KEY PARAMETERS (METRIC UNITS)
  -------------VEHICLE-----------  ----------STRATEGY-----------
   WB    WT    CDA   TTIRE PTIRE  ACLFAC  ACLRCS  FBRKS  NREGEN  EFFCM  EFFCFW
   489  1757  0.600  RADIAL 38.0   0.50   -0.67    0.30    2     0.000  0.585

--------------MODELS----------------
DRCOUP  ANALYT  NI-FE1.0    EV

ITERATION NUMBER  2 NAMCYC = HIWAY

ITERATION NUMBER  3 NAMCYC = HIWAY

ITERATION NUMBER  4 NAMCYC = HIWAY
```

PARKING FOR 7.040 HOURS

ITERATION NUMBER 1 NAMCYC = FEDRAL
FEURAL SCHUDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
FEDRAL CYCLE. 1372 VALUES READ.

ITERATION NUMBER 1 NAMCYC = HIWAY
HIWAY SCHDDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
HIWAY CYCLE. 766 VALUES READ.

ITERATIUN NUMBER 1 NAMCYC = FEDRAL
FEDRAL SCHDDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
FEDRAL CYCLE. 1372 VALUES READ.

PARKING FOR 0.660 HOURS

ITERATION NUMBER 1 NAMCYC = FEDRAL

PARKING FOR 14.090 HOURS

SCHEDULE	PERIOD	RANGE	AVERAGE SPEED	ROAD ENERGY W/O RGN	ROAD ENERGY W RGN	MAX ROAD POWER
	SEC	MI	MI/H	WH/MI	WH/MI	HP
HIWAY	86382	73.635	3.1	181.2	132.6	50.6

ENERGY AND EFFICIENCY SUMMARY FOR RANGE TRAVELED-

MAJOR SUBSYSTEM LOSSES AND EFFICIENCIES-

	BATT SYS	MTR/CNT	DRVTRN	PWRTRN	BRAKES	MISC
WH/MI	205.5	27.0	23.8	50.8	15.8	2.5
PRCNT(PWRTRN)	404.6	53.1	46.9	100.0	31.1	5.0
PRCNT(OVERALL)	50.5	6.6	5.8	12.5	3.9	0.6
EFFICIENCY	0.525	0.894	0.899	0.808		

COMPONENT LOSS BY DRIVING PHASE(WH/MI AND PERCENT OF OVERALL)-

	TOTAL	ACCEL	CRUISE	COAST	BRAKE	DWELL
OVERALL,WH/MI	407.2					
EFFICIENCY	0.364					
MOTOR	27.0	15.5	3.4	0.0	8.1	0.0
PERCENT	6.6	3.8	0.8	0.0	2.0	0.0
EFFICIENCY	0.894	0.906	0.885	0.000	0.864	0.000
TRANSMISSION	23.8	15.1	2.7	0.0	6.1	0.0
PERCENT	5.8	3.7	0.7	0.0	1.5	0.0
EFFICIENCY	0.899	0.900	0.899	0.000	0.896	0.000
AERO	70.1	28.4	13.5	0.0	28.2	0.0
PERCENT	17.2	7.0	3.3	0.0	6.9	0.0
TIRES	62.5	27.1	10.2	0.0	25.1	0.0
PERCENT	15.3	6.7	2.5	0.0	6.2	0.0
MISCELLAN	2.5	0.1	0.0	0.0	0.1	2.3
PERCENT	0.6	0.0	0.0	0.0	0.0	0.6

BATTERY AND CHARGER

ENERGY OUT	ENERGY IN	ENERGY LOSS		POWER,MX OUT	POWER,MX IN	FINAL STATE	BATT EFF	CHARGER LOSS		CHARGER EFF
WH/MI	WH/MI	WH/MI	PRCNT	W/LB	W/LB			WH/MI	PRCNT	
227	26	165	40.5	41.2	24.3	0.000	0.58	41	10.00	0.900

```
    TOTAL       ELECT CONSM       ELECT COST
    RANGE         AT WALL       (AT 10.0C/KWH)
     MI       WH/MI  WH/MI*TON      C/MI

    134.4    407.2    210.3          4.07
    106.7 *

* - BASED ON LOWEST DEPTH OF DISCHARGE ( 0.794)WHICH COULD
    SUSTAIN THE MAXIMUM POWER DENSITY (  90.9 W/KG).

EQUIVALENT FUEL CONSUMPTION AND ECONOMY (GASOLINE)-

   SOURCE OF       CONSUMPTION      ECONOMY
 PRIMARY ENERGY      LIT/KM      KM/LIT  MI/GAL
   PETROLEUM         0.07724      12.9    30.4
   COAL              0.04466      22.4    52.7

DO YOU WANT THE CAFE VALUE COMPUTED?
>
N


******************************************************************************

 INPUT CHANGES FOR NEXT RUN-
>
PARAMVAR
INPUT NAME OF PARAMETER, INITIAL VALUE, FINAL VALUE, AND NUM STEPS-
>
NAMCYC
DO YOU WANT A SUMMARY OF THE URBAN SUBSEGMENTS (Y OR N)?
>
N
INPUT NAME AND NUMBER OF CYCLES. INPUT END WHEN DONE.
FOR 'PARK' AND 'IDLE' CYCLES, INPUT NAME AND PERIOD
>
HIWAY 4
>
PARK 6.5HR
>
FEDRAL 1
>
HIWAY 4
>
FEDRAL 1
>
PARK 15.04HR
>
END
>
RUN
 INPUT COMPLETE FOR THIS CASE
 INPUT A 1-78 CHARACTER TITLE FOR THIS CASE-
>
```

TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC - CYCLE 10
DATE 4-OCT-84
TIME 12:08:07

ITERATION NUMBER 1 NAMCYC = HIWAY
HIWAY SCHDDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
HIWAY CYCLE. 766 VALUES READ.

KEY PARAMETERS (METRIC UNITS)

------------	------------VEHICLE	------------			------------	------------STRATEGY	------------			
WB	WT	CDA	TTIRE	PTIRE	ACLFAC	ACLRCS	FBRKS	NREGEN	EFFCM	EFFCFW
489	1757	0.600	RADIAL	38.0	0.50	-0.67	0.30	2	0.000	0.585

--------------MODELS----------------
DRCOUP ANALYT NI-FE1.0 EV

ITERATION NUMBER 2 NAMCYC = HIWAY

ITERATION NUMBER 3 NAMCYC = HIWAY

ITERATION NUMBER 4 NAMCYC = HIWAY

PARKING FOR 6.500 HOURS

ITERATION NUMBER 1 NAMCYC = FEDRAL
FEDRAL SCHDDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
FEDRAL CYCLE. 1372 VALUES READ.

ITERATION NUMBER 1 NAMCYC = HIWAY
HIWAY SCHDDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
HIWAY CYCLE. 766 VALUES READ.

ITERATION NUMBER 2 NAMCYC = HIWAY

ITERATION NUMBER 3 NAMCYC = HIWAY

ITERATION NUMBER 4 NAMCYC = HIWAY

ITERATION NUMBER 1 NAMCYC = FEDRAL
FEDRAL SCHDDATA NOT CURRENTLY IN CORE
SEARCHING BULKDATA FILE FOR IT.
FEDRAL CYCLE. 1372 VALUES READ.

PARKING FOR 15.040 HOURS

SCHEDULE	PERIOD	RANGE	AVERAGE SPEED	ROAD ENERGY W/O RGN	ROAD ENERGY W RGN	MAX ROAD POWER
	SEC	MI	MI/H	WH/MI	WH/MI	HP
HIWAY	86406	96.954	4.0	176.7	140.1	50.6

ENERGY AND EFFICIENCY SUMMARY FOR RANGE TRAVELED-

MAJOR SUBSYSTEM LOSSES AND EFFICIENCIES-

	BATT SYS	MTR/CNT	DRVTRN	PWRTRN	BRAKES	MISC
WH/MI	199.7	24.6	22.4	47.0	11.8	1.9

PRCNT(PWRTRN)	424.8	52.4	47.6	100.0	25.0	4.1
PRCNT(OVERALL)	49.9	6.1	5.6	11.7	2.9	0.5
EFFICIENCY	0.525	0.898	0.899	0.811		

COMPONENT LOSS BY DRIVING PHASE(WH/MI AND PERCENT OF OVERALL)-

	TOTAL	ACCEL	CRUISE	COAST	BRAKE	DWELL
OVERALL,WH/MI	400.5					
EFFICIENCY	0.379					
MOTOR	24.6	13.7	3.6	0.0	7.2	0.0
PERCENT	6.1	3.4	0.9	0.0	1.8	0.0
EFFICIENCY	0.898	0.911	0.887	0.000	0.868	0.000
TRANSMISSION	22.4	14.0	2.9	0.0	5.5	0.0
PERCENT	5.6	3.5	0.7	0.0	1.4	0.0
EFFICIENCY	0.899	0.900	0.899	0.000	0.897	0.000
AERO	77.5	31.4	15.2	0.0	30.9	0.0
PERCENT	19.3	7.8	3.8	0.0	7.7	0.0
TIRES	62.6	27.0	10.8	0.0	24.8	0.0
PERCENT	15.6	6.7	2.7	0.0	6.2	0.0
MISCELLAN	1.9	0.1	0.0	0.0	0.1	1.7
PERCENT	0.5	0.0	0.0	0.0	0.0	0.4

---------------------BATTERY AND CHARGER---------------------

--------ENERGY------				POWER,MX		FINAL	BATT	-----CHARGER-----		
OUT	IN	LOSS		OUT	IN	STATE	EFF	LOSS		EFF
WH/MI	WH/MI	WH/MI	PRCNT	W/LB				WH/MI	PRCNT	
220	20	160	39.9	41.2	24.3	0.000	0.58	40	10.00	0.900

TOTAL RANGE MI	ELECT CONSM AT WALL WH/MI	WH/MI*TON	ELECT COST (AT 10.0C/KWH) C/MI
135.7	400.5	206.8	4.01
107.7 *			

* - BASED ON LOWEST DEPTH OF DISCHARGE (0.794)WHICH COULD SUSTAIN THE MAXIMUM POWER DENSITY (90.9 W/KG).

EQUIVALENT FUEL CONSUMPTION AND ECONOMY (GASOLINE)-

SOURCE OF PRIMARY ENERGY	CONSUMPTION LIT/KM	ECONOMY KM/LIT	MI/GAL
PETROLEUM	0.07689	13.0	30.6
COAL	0.04445	22.5	52.9

DO YOU WANT THE CAFE VALUE COMPUTED?
>
N

****

INPUT CHANGES FOR NEXT RUN-
>
QUIT
GRCUSER   Job terminated at 4-OCT-1984 12:14:56.78

Accounting information:

Buffered I/O count:	115	Peak working set size:	529
Direct I/O count:	1963	Peak page file size:	493
Page faults:	1290	Mounted volumes:	0
Elapsed CPU time:	0 00:09:46.38	Elapsed time:	0 02:30:58.90

```
$ type eltest.ran

    101.8,    80.9,0.794, 90.9,   537.2,  0.0000, " 4-OCT-84","09:57:06"
    119.9,    95.2,0.794, 90.9,   475.8,  0.0000, " 4-OCT-84","09:58:00"
    118.7,    94.3,0.794, 90.9,   469.0,  0.0000, " 4-OCT-84","10:04:01"
    123.1,    97.7,0.794, 90.9,   450.5,  0.0000, " 4-OCT-84","10:06:04"
    127.1,   100.9,0.794, 90.9,   443.8,  0.0000, " 4-OCT-84","10:17:22"
    126.5,   100.4,0.794, 90.9,   442.2,  0.0000, " 4-OCT-84","11:44:35"
    129.4,   102.7,0.794, 90.9,   435.3,  0.0000, " 4-OCT-84","11:56:06"
    129.4,   102.7,0.794, 90.9,   434.7,  0.0000, " 4-OCT-84","12:02:44"
    134.4,   106.7,0.794, 90.9,   407.2,  0.0000, " 4-OCT-84","12:08:04"
    135.7,   107.7,0.794, 90.9,   400.5,  0.0000, " 4-OCT-84","12:14:51"

$ log
```

(ELTEST.RAN)

TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC

ELTEST.RAN

101.8	80.9	.794	90.9	537.2	0	4-OCT-84	09:57:06
119.9	95.2	.794	90.9	475.8	0	4-OCT-84	09:58:00
118.7	94.3	.794	90.9	469	0	4-OCT-84	10:04:01
123.1	97.7	.794	90.9	450.5	0	4-OCT-84	10:06:04
127.1	100.9	.794	90.9	443.8	0	4-OCT-84	10:17:22
126.5	100.4	.794	90.9	442.2	0	4-OCT-84	11:44:35
129.4	102.7	.794	90.9	435.3	0	4-OCT-84	11:56:06
129.4	102.7	.794	90.9	434.7	0	4-OCT-84	12:02:44
134.4	106.7	.794	90.9	407.2	0	4-OCT-84	12:08:04
135.7	107.7	.794	90.9	400.5	0	4-OCT-84	12:14:51

cycle	wh/mile	miles/day	days	cum miles	kwh	DOD	cycles	
1	537.2	4.2	57	239.4	128.6057	4.125736E-02		2.35167
2	475.8	7.45	50	372.5	177.2355	6.213511E-02		3.106756
3	469	8.2	43	352.6	165.3694	6.908171E-02		2.970514
4	450.5	16.86	32	539.52	243.0538	.1369618	4.382778	
5	443.8	22.35	63	1408.05	624.8926	.1758458	11.07828	
6	442.2	27	27	729	322.3638	.2134387	5.762846	
7	435.3	45.4	29	1316.6	573.116	.3508501	10.17465	
8	434.7	59.6	18	1072.8	466.3462	.4605874	8.290572	
9	407.2	73.6	19	1398.4	569.4285	.5476191	10.40476	
10	400.5	105.5	8	844	338.022	.7774503	6.219602	

8272.87 miles on electric   3608.433 Kw-hrs   64.74244 cycles   0   FUEL MILES   0

Electric...   0   Fuel...   0

Annual travel in Km= 13236.59

Battery Cycle Life= 750 Cycles

Depth of discharge Average Daily= .1773765

(AVENERGY OUTPUT REPORT)

```
          ELECTRIC AND HYBRID VEHICLE COST MODEL

       TEST CASE - 5 PAS - NI-FE1.0 - 100MI. DESIRED RANGE - ELECTRIC          10-14-1984

                               *--INPUTS--*

 GENERAL --                              YEAR:      1982
VEHICLE SIZE:  5-PASS                    REAL INTEREST RATE:   10 %
CURB WEIGHT:  1620.06 KG                 VEHICLE SALVAGE VALUE:     10 %
VEHICLE WEIGHT , WT:   1756.06
LIFE:               132365.9 KM          ACCESSORY COST:   $ 200

 BATTERY --                              NAME:   NI-FE1.0
BATTERY WEIGHT:     409.0176 KG          BATTERY CYCLE LIFE:   750
ELECTRICITY COST:     .05 $/KW-H         MAXIMUM SHELF LIFE:    10 YEARS
AVERAGE DAILY DEPTH OF DISCHARGE:   .1773765
                                         DEPTH OF A DEEP DISCHARGE:   .8

MAINTENANCE FACTOR:   1

TRANSMISSION TYPE:  CVT
 MOTOR --
RATED POWER:          44.27287 KW        TYPE:        AC
CONTROLLER:         49.19208  KW

 DRIVING --                              AMOUNT:    13236.57 KM/YEAR
ANNUAL ELEC USE:     3608.433 KW-H

                              *-- OUTPUTS --*


COST ITEMS-
                             $      C/KM
BASIC VEHICLE COST        6990.79  5.281
MOTOR COST                 841.10  0.635
CONTROLLER COST           2213.64  1.672
EV TRANSMISSION COST       549.48  0.415
BATTERY      LOW          5264.78  3.977  HIGH 5785.48  4.371
                          -------  -----
INITIAL COST      LOW    15857.08 11.982  HIGH16380.58 12.375
DOWNPAYMENT     LOW       3171.98  2.396  HIGH 3276.12  2.475


REPLACEM'T BATTS LOW      5264.78  3.977  HIGH 5785.48  4.371
REPAIRS & MAINTENANCE     2326.27  1.757
REPLACEMENT TIRES          349.54  0.264
INSURANCE                 3479.00  2.628
GARAGING,PARK, TOLL        782.50  0.591
TITLE, REG, LIC, LOW.      992.99  0.750  HIGH 1019.03  0.770
ELECTRICITY               1804.22  1.363
PRIN & INT LOW           12687.91  9.585  HIGH13104.46  9.900
                          -------  -----
OPERATING COST  LOW      27687.22 20.917  HIGH28129.01 21.252


VEHICLE SALVAGE VALUE  LOW 5257.14  3.972  HIGH 5736.40  4.334
BATTERY SALVAGE  LOW        179.65  0.136  HIGH  179.65  0.136


TOTAL LIFE CYCLE COST  LOW25422.41 19.206  HIGH25489.60 19.257
```

(AVCOST OUTPUT REPORT)

LISTING

```
10 KEY OFF:CLS
20 '************************************************************************
*
30 '
40 '                              ** AVSIZING **
50 '         SIZES A PRELIMINARY VEHICLE TARGETED TO A DESIRED RANGE.
60 '
70 '
80 '************************************************************************

90 '
100 '
110 PRINT TAB(24)"WELCOME TO THE AVSIZING PROGRAM"
120 PRINT : PRINT
130 DIM CON(6),U$(20),CY$(12),PE$(4),CH(3),BATN$(4),DOM(50),RAN(50)
140 ERRORF%=0
150 '
160 REM PROMPT FOR THE INPUT DATA
170 '
180 PRINT "DO YOU WISH TO RUN :"
190 PRINT "    1. NEW VEHICLE USING AN URBAN OR HIGHWAY CYCLE?" : PRINT "    2. PR
EVIOUS VEHICLE USING A 24. HR CYCLE?" : PRINT "    3. REDESIGN OF VEHICLE BY CHAN
GING THE BMF?"
200 INPUT "       ENTER TYPE OF RUN (1,2, OR 3) : " , TOR%
210 IF TOR%<>1 AND TOR%<>2 AND TOR%<>3 THEN 200
220 '
230 REM OPEN FILE VEHICLE.DAT
240 '
250 IF TOR%=1 THEN 370
260 OPEN "VEHICLE.DAT" FOR INPUT AS #2
270 INPUT#2, TLE$, CAP%, VEH%, ICWT, DRAN, NUM%, SNUM%, CDA, CNUM%, BMF1, BMF2,
PTOR%
280 CLOSE #2
290 IF TOR%=2 THEN 1000
300 '
310 '
320 PRINT : PRINT
330 PRINT "  ENTER A VALUE BETWEEN";BMF1;" AND 0.45"
340 PRINT : PRINT
350 INPUT "ENTER BMF : " , BMFIN
360 GOTO 1000
370 '
380 REM SET RUN FLAG TO ZERO. (FIRST RUN)
390 '
400 RF%=0
410 PRINT : PRINT
420 PRINT "ENTER TITLE OF RUN( 67 CHARACTERS OR LESS - DO NOT USE COMMAS )"
430 INPUT "TITLE : ", TLE$
440 PRINT
450 PRINT "VEHICLE CAPACITY"
460 PRINT STRING$(14,196)
470 PRINT "2,4,5 OR 6 PASSENGERS"
480 PRINT "IF THE VEHICLE IS A VAN THEN SET CAPACITY EQUAL TO 6"
490 INPUT "ENTER VEHICLE CAPACITY(PASSENGERS) : " , CAP%
500 '
510 REM IF INVALID NUMBER OF PASSENGERS THEN TRY AGAIN
520 '
530 IF CAP%<>2 AND CAP%<>4 AND CAP%<>5 AND CAP%<>6 THEN 490
540 IF CAP%=2 OR CAP%=6 THEN VEH%=1
550 IF CAP%=2 OR CAP%=6 THEN GOTO 650
560 PRINT
570 PRINT "VEHICLE TYPE"
580 PRINT STRING$(12,196)
```

PRECEDING PAGE BLANK NOT FILMED

PAGE M-70 INTENTIONALLY BLANK

```
590 PRINT "   1. ELECTRIC VEHICLE" :PRINT "   2. HYBRID VEHICLE"
600 INPUT "      ENTER VEHICLE TYPE (1 OR 2) : " , VEH%
610 '
620 REM IF INVALID VEHICLE TYPE NUMBER THEN TRY AGAIN
630 '
640 IF VEH%<>1 AND VEH%<>2 THEN 600
650 CLS
660 PRINT
670 PRINT
680 INPUT "ENTER DESIRED RANGE(MI) : " , DRAN
690 '
700 REM INPUTS FOR THE DC OPTION. (NOT CURRENTLY AVAILABLE.)
710 '
720 REM PRINT
730 REM PRINT "MOTOR TYPE "
740 REM PRINT STRING$(10,196)
750 REM PRINT "1. AC" : PRINT "2. DC"
760 REM INPUT "ENTER MOTOR TYPE NUMBER :  ", MT%
770 '
780 REM IF INVALID MOTOR TYPE NUMBER THEN TRY AGAIN.
790 '
800 REM IF MT%<>1 AND MT%<>2 THEN 350
810 '
820 PRINT
830 PRINT "BATTERY TYPE NUMBER LIST"
840 PRINT STRING$(24,196)
850 PRINT "   1. AL-AIR" : PRINT "   2. FE-AIR" : PRINT "   3. LI-FE-S" : PRINT
"   4. LI-FE-S2"
860 PRINT "   5. NA-S" : PRINT "   6. NI-FE" : PRINT "   7. NI-ZN"
870 PRINT "   8. PB-AC/ADV" : PRINT "   9. PB-AC/BIPL" : PRINT "  10. ZN-BR"
880 PRINT "  11. ZN-CL2"
890 INPUT "   ENTER BATTERY TYPE NUMBER : " , NUM%
900 '
910 REM IF INVALID BATTERY NUMBER THEN TRY AGAIN
920 '
930 IF NUM%<>1 AND NUM%<>2 AND NUM%<>3 AND NUM%<>4 AND NUM%<>5 AND NUM%<>6 AND N
UM%<>7 AND NUM%<>8 AND NUM%<>9 AND NUM%<>10 AND NUM%<>11 THEN 890
940 PRINT
950 PRINT "POWER TO ENERGY RATIO"
960 PRINT STRING$(20,196)
970 PRINT "   1. P/E = 1.0" : PRINT "   2. P/E = 2.1" : PRINT "   3. P/E = 2.4"
: PRINT "   4. P/E = 3.3"
980 INPUT "   ENTER POWER TO ENERGY RATIO NUMBER : " ,SNUM%
990 IF SNUM%<>1 AND SNUM%<>2 AND SNUM%<>3 AND SNUM%<>4 THEN 980
1000 CLS : PRINT : PRINT : PRINT
1010 PRINT "DO YOU WISH TO RUN ELVEC IN : " : PRINT "   1. DEMAND" : PRINT "
 2. BATCH"
1020 INPUT "ENTER TYPE OF RUN(1 OR 2) : " , DOB%
1030 IF DOB%<>1 AND DOB%<>2 THEN 1020
1040 IF TOR%=2 THEN CLS
1050 IF TOR%=2 THEN PRINT
1060 IF TOR%=2 THEN PRINT
1070 IF TOR%=2 AND DOB%=2 THEN INPUT "ENTER FILENAME OF 24 HR. INPUT FILE : ", N
AM24$ ELSE NAM24$="STAREL"
1080 '
1090 REM INPUT RANGE FOR 5 PAS VEHICLE.
1100 '
1110 IF TOR%=2 AND CAP%=5 THEN CLS
1120 IF TOR%=2 AND CAP%=5 THEN PRINT
1130 IF TOR%=2 AND CAP%=5 THEN PRINT
1140 IF TOR%=2 AND CAP%=5 THEN PRINT "RANGES FOR 5 PAS VEHILCLE"
1150 IF TOR%=2 AND CAP%=5 THEN PRINT STRING$(25,196)
1160 IF TOR%=2 AND CAP%=5 THEN PRINT "   1. 100 MI  VEHICLE" : PRINT "   2. 150
```

```
MI. VEHICLE" : PRINT "   3. 250 MI. VEHICLE"
1170 IF TORX=2 AND CAPX=5 THEN INPUT "ENTER VEHICLE RANGE NO.(1,2 OR 3) : " , SC
APX
1180 IF TORX=2 AND CAPX=5 THEN IF SCAPX<>1 AND SCAPX<>2 AND SCAPX<>3 THEN 1170
1190 IF CAPX=2 THEN CYCLEX=9
1200 IF CAPX=5 AND SCAPX=1 THEN CYCLEX=10
1210 IF CAPX=5 AND SCAPX=2 THEN CYCLEX=11
1220 IF CAPX=5 AND SCAPX=3 THEN CYCLEX=12
1230 IF CAPX=4 THEN CYCLEX=12
1240 CLS
1250 REM SET MTX=1 FOR THE AC OPTION ONLY.
1260 '
1270 MTX=1
1280 IF NUMX=1 THEN 1440 'BRANCH TO AL-AIR DATA SET
1290 IF NUMX=2 THEN 1530 'BRANCH TO FE-AIR DATA SET
1300 IF NUMX=3 THEN 1780 'BRANCH TO LI-FE-S DATA SET
1310 IF NUMX=4 THEN 2030 'BRANCH TO LI-FE-S2 DATA SET
1320 IF NUMX=5 THEN 2100 'BRANCH TO NA-S DATA SET
1330 IF NUMX=6 THEN 2350 'BRANCH TO NI-FE DATA SET
1340 IF NUMX=7 THEN 2600 'BRANCH TO NI-ZN DATA SET
1350 IF NUMX=8 THEN 2700 'BRANCH TO PB-AC/ADV DATA SET
1360 IF NUMX=9 THEN 2950 'BRANCH TO PB-AC/BIPL DATA SET
1370 IF NUMX=10 THEN 3170 'BRANCH TO ZN-BR DATA SET
1380 IF NUMX=11 THEN 3420 'BRANCH TO ZN-CL2 DATA SET
1390 '
1400 REM BATTERY DATA SETS
1410 ' DATA SETS CONTAIN MASS DENSITY, SPECIFIC ENERGY AND SPECIFIC POWER -
1420 ' FOLLOWED BY THE CH COEFFICIENTS.
1430 '
1440 NAM$ = "AL-AIR" : EFFCD=.18 : SLFD=0 : ACC=5!
1450 DATA 0.21,.107,158,165,157
1460 DATA 4.9078,-.723055,-.0984402
1470 RESTORE 1450
1480 READ A,B,Q1,Q2,PBC
1490 RESTORE 1460
1500 GOSUB 9990
1510 GOTO 3660
1520 '
1530 DATA "FE-AIR1.0","FE-AIR2.1","FE-AIR2.4","FE-AIR3.3" : EFFCD=.5
1540 SLFD=.04 : ACC=1.67
1550 RESTORE 1530
1560 GOSUB 10000
1570 NAM$=BATN$(SNUMX)
1580 DATA .12,3.671,109,148,110
1590 DATA .216,.202,68,74,140
1600 DATA .225,.393,68,54,157
1610 DATA .292,.398,52,75,165
1620 DATA 4.48115,-.723875,-.0850794
1630 DATA 4.12545,-.833583,-.0698404
1640 DATA 4.13931,-.858481,-.0612641
1650 DATA 3.90664,-.886569,-.0563951
1660 IF SNUMX=1 THEN RESTORE 1580
1670 IF SNUMX=2 THEN RESTORE 1590
1680 IF SNUMX=3 THEN RESTORE 1600
1690 IF SNUMX=4 THEN RESTORE 1610
1700 READ A,B,Q1,Q2,PBC
1710 IF SNUMX=1 THEN RESTORE 1620
1720 IF SNUMX=2 THEN RESTORE 1630
1730 IF SNUMX=3 THEN RESTORE 1640
1740 IF SNUMX=4 THEN RESTORE 1650
1750 GOSUB 9990
1760 GOTO 3660
1770 '
```

```
1780 DATA "LI-FE-S1.0","LI-FE-S2.1","LI-FE-S2.1","LI-FE-S3.3" ! EFFCD=.6
1790 SLFD=0! ! ACC=0
1800 RESTORE 1780
1810 GOSUB 10080
1820 NAM$=BATN$(SNUM%)
1830 DATA .119,4.386,102,190,161
1840 DATA .119,4.39,81,190,165
1850 DATA .119,4.39,81,190,165
1860 DATA .134,4.181,71,190,175
1870 DATA 4.37983,-.713407,-.0835533
1880 DATA 4.21177,-.748451,-.0864695
1890 DATA 4.21177,-.748451,-.0864695
1900 DATA 4.13332,-.79485,-.081334
1910 IF SNUM%=1 THEN RESTORE 1830
1920 IF SNUM%=2 THEN RESTORE 1840
1930 IF SNUM%=3 THEN RESTORE 1850
1940 IF SNUM%=4 THEN RESTORE 1860
1950 READ A,B,Q1,Q2,PBC
1960 IF SNUM%=1 THEN RESTORE 1870
1970 IF SNUM%=2 THEN RESTORE 1880
1980 IF SNUM%=3 THEN RESTORE 1890
1990 IF SNUM%=4 THEN RESTORE 1900
2000 GOSUB 9990
2010 GOTO 3660
2020 '
2030 PRINT : PRINT : PRINT
2031 PRINT "The battery LI-FE-S2 is not currently available."
2032 GOTO 7350
2035 NAM$ = "LI-FE-S2" : EFFCD=.45
2040 ACC=0
2050 DATA 2.2,110.,144,
2060 RESTORE 2050
2070 READ MU,ED,PD
2080 GOTO 3660
2090 '
2100 DATA "NA-S1.0","NA-S2.1","NA-S2.4","NA-S3.3" ! EFFCD=.66
2110 SLFD=0! ! ACC=0
2120 RESTORE 2100
2130 GOSUB 10080
2140 NAM$=BATN$(SNUM%)
2150 DATA .216,-2.88,121,133,148
2160 DATA .134,1.897,87,94,199
2170 DATA .141,1.717,83,75,224
2180 DATA .134,4.181,73,81,244
2190 DATA 4.57375,-.790541,-.0409?3
2200 DATA 4.36547,-.884157,-.0299437
2210 DATA 4.3308,-.894503,-.027496A
2220 DATA 4.21601,-.902732,-.0272804
2230 IF SNUM%=1 THEN RESTORE 2150
2240 IF SNUM%=2 THEN RESTORE 2160
2250 IF SNUM%=3 THEN RESTORE 2170
2260 IF SNUM%=4 THEN RESTORE 2180
2270 READ A,B,Q1,Q2,PBC
2280 IF SNUM%=1 THEN RESTORE 2190
2290 IF SNUM%=2 THEN RESTORE 2200
2300 IF SNUM%=3 THEN RESTORE 2210
2310 IF SNUM%=4 THEN RESTORE 2220
2320 GOSUB 9990
2330 GOTO 3660
2340 '
2350 DATA "NI-FE1.0","NI-FE2.1","NI-FE2.1","NI-FE3.3" ! EFFCD=.58
2360 SLFD=.016 ! ACC=0
2370 RESTORE 2350
```

```
2380 GOSUB 10080
2390 NAM$=DATN$(SNUM%)
2400 DATA .195,3.836,56,102,120
2410 DATA .205,3.536,54,92,141
2420 DATA .205,3.536,52,87,141
2430 DATA .229,2.878,48,93,160
2440 DATA 3.85854,-.723694,-.00985473
2450 DATA 3.9014,-.802984,-.0824347
2460 DATA 3.87467,-.820591,-.0747063
2470 DATA 3.81662,-.882478,-.0504292
2480 IF SNUM%=1 THEN RESTORE 2400
2490 IF SNUM%=2 THEN RESTORE 2410
2500 IF SNUM%=3 THEN RESTORE 2420
2510 IF SNUM%=4 THEN RESTORE 2430
2520 READ A,B,Q1,Q2,PBC
2530 IF SNUM%=1 THEN RESTORE 2440
2540 IF SNUM%=2 THEN RESTORE 2450
2550 IF SNUM%=3 THEN RESTORE 2460
2560 IF SNUM%=4 THEN RESTORE 2470
2570 GOSUB 9990
2580 GOTO 3660
2590 '
2600 NAM$ = "NI-ZN2.0" : EFFCD=.7
2610 SLFD=0 : ACC=0
2620 DATA .171,6.784,60,100,54
2630 DATA 4.06488,-.844001,-.0847194
2640 RESTORE 2620
2650 READ A,B,Q1,Q2,PBC
2660 RESTORE 2630
2670 GOSUB 9990
2680 GOTO 3660
2690 '
2700 DATA "PBAC/AD1.0","PBAC/AD2.1","PBAC/AD2.1","PBAC/AD3.3" : EFFCD=.75
2710 SLFD=0 : ACC=0
2720 RESTORE 2700
2730 GOSUB 10080
2740 NAM$=DATN$(SNUM%)
2750 DATA .224,8.226,45,99,120
2760 DATA .241,7.137,43,91,135
2770 DATA .241,7.137,41,86,135
2780 DATA .286,4.8,38,90,145
2790 DATA 3.66561,-.705735,-.110161
2800 DATA 3.65425,-.725333,-.121204
2810 DATA 3.62408,-.782033,-.0989376
2820 DATA 3.57472,-.822528,-.0838422
2830 IF SNUM%=1 THEN RESTORE 2750
2840 IF SNUM%=2 THEN RESTORE 2760
2850 IF SNUM%=3 THEN RESTORE 2770
2860 IF SNUM%=4 THEN RESTORE 2780
2870 READ A,B,Q1,Q2,PBC
2880 IF SNUM%=1 THEN RESTORE 2790
2890 IF SNUM%=2 THEN RESTORE 2800
2900 IF SNUM%=3 THEN RESTORE 2810
2910 IF SNUM%=4 THEN RESTORE 2820
2920 GOSUB 9990
2930 GOTO 3660
2940 '
2950 NAM$="PB-AC/BIPL" : EFFCD=.85
2960 SLFD=0 :ACC=0
2970 DATA .26,3.0,50,99,400
3010 DATA 3.84895,-.890158,-.0380122
3050 RESTORE 2970
3090 READ A,B,Q1,Q2,PBC
```

```
3100 RESTORE 3010
3140 GOSUB 9990
3150 GOTO 3660
3160 '
3170 DATA "ZN-BR2/1.0","ZN-BR2/2.1","ZN-BR2/2.4","ZN-BR2/3.3" : EFFCD=.56
3180 SLFD=.08 : ACC=1.12
3190 RESTORE 3170
3200 GOSUB 10080
3210 NAM$=BATN$(SNUM%)
3220 DATA .145,9.392,6,91,83
3230 DATA .244,4.402,48,62,115
3240 DATA .253,2.526,49,49,135
3250 DATA .32,2.678,40,53,150
3260 DATA 4.[illegible]37,-.627864,-.151306
3270 DATA 3.[illegible]9,-.819456,-.0951689
3280 DATA 3.8[illegible]12,-.837169,-.0851764
3290 DATA 3.65918,-.874489,-.0779032
3300 IF SNUM%=1 THEN RESTORE 3220
3310 IF SNUM%=2 THEN RESTORE 3230
3320 IF SNUM%=3 THEN RESTORE 3240
3330 IF SNUM%=4 THEN RESTORE 3250
3340 READ A,B,Q1,Q2,PBC
3350 IF SNUM%=1 THEN RESTORE 3260
3360 IF SNUM%=2 THEN RESTORE 3270
3370 IF SNUM%=3 THEN RESTORE 3280
3380 IF SNUM%=4 THEN RESTORE 3290
3390 GOSUB 9990
3400 GOTO 3660
3410 '
3420 DATA "ZN-CL2/1.0","ZN-CL2/2.1","ZN-CL2/2.4","ZN-CL2/3.3" : EFFCD=.53
3430 SLFD=.02 : ACC=.44
3440 RESTORE 3420
3450 GOSUB 10080
3460 NAM$=BATN$(SNUM%)
3470 DATA .127,2.882,89,111,86
3480 DATA .214,2.766,54,64,110
3490 DATA .215,2.242,54,48,127
3500 DATA .278,2.066,42,56,130
3510 DATA 4.2577,-.658475,-.117385
3520 DATA 3.90924,-.820198,-.0882068
3530 DATA 3.9258,-.848145,-.0752426
3540 DATA 3.69598,-.878004,-.0750732
3550 IF SNUM%=1 THEN RESTORE 3470
3560 IF SNUM%=2 THEN RESTORE 3480
3570 IF SNUM%=3 THEN RESTORE 3490
3580 IF SNUM%=4 THEN RESTORE 3500
3590 READ A,B,Q1,Q2,PBC
3600 IF SNUM%=1 THEN RESTORE 3510
3610 IF SNUM%=2 THEN RESTORE 3520
3620 IF SNUM%=3 THEN RESTORE 3530
3630 IF SNUM%=4 THEN RESTORE 3540
3640 GOSUB 9990
3650 GOTO 3660
3660 '
3670 '
3680 REM BASIC EQUATIONS (DEFINE VEHICLE PARAMETERS)
3690 '
3700 IF VEH%=1 THEN VT$="ELECTRIC"
3710 IF VEH%=2 THEN VT$="  HYBRID"
3720 IF CAP%=2 THEN WSH=451
3730 IF CAP%=4 THEN WSH=596
3740 IF CAP%=5 THEN WSH=797
3750 IF CAP%=6 THEN WSH=989
```

```
3760 IF CAP%=2 THEN GRADE=17.5
3770 IF CAP%=2 THEN ACCN= 21.5
3780 IF CAP%=2 THEN CYCLE=25.9
3790 IF CAP%=4 OR CAP%=5 THEN GRADE=28
3800 IF CAP%=4 OR CAP%=5 THEN ACCN=24
3810 IF CAP%=4 OR CAP%=5 THEN CYCLE=26
3820 IF CAP%=6 THEN GRADE=20.3
3830 IF CAP%=6 THEN ACCN=20.3
3840 IF CAP%=6 THEN CYCLE=20.3
3850 MOTSW=490 : CONSW=2500 : TRFSW=.418 : TRCVTSW=1096 : HESW=450
3860 WMOT1=.9000001*GRADE/MOTSW
3870 IF CAP%=4 OR CAP%=5 THEN WCON1=GRADE/CONSW
3880 IF CAP%=5 THEN WTF1=GRADE/TRFSW
3890 IF CAP%=2 OR CAP%=6 THEN WCON1=CYCLE/CONSW
3900 IF CAP%=2 OR CAP%=6 THEN WTF1=CYCLE/TRFSW
3910 IF CAP%=4 THEN WTF1=GRADE/TRFSW
3920 IF CAP%=4 AND VEH%=2 THEN WTCVT1=GRADE/TRCVTSW
3930 IF CAP%=5 AND VEH%=2 THEN WTCVT1=GRADE/TRCVTSW
3940 IF VEH%=1 THEN WTCVT1=0 ELSE WTCVT1=GRADE/TRCVTSW
3950 IF VEH%=2 THEN WHE1=GRADE/HESW ELSE WHE1=0
3960 IF VEH%=1 THEN WTR1= WTF1 ELSE WTR1=WTF1+WTCVT1
3970 IF CAP%=6 THEN PANDPL=295 ELSE PANDPL=136
3980 IF PTOR%=3 AND TOR%=2 THEN GOTO 4190
3990 IF TOR%=3 THEN GOTO 4170
3991 '
3992 REM ITERATION PROCEDURE FOR ACTUAL RANGE.
3993 '
4000 R=1.2*DRAN
4020 ICOUNT%=1
4025 REM COMPUTE BMF AS A FUNCTION OF ELVEC RANGE
4030 BMF=(A*R+B)/100
4035 IF NUM%=1 THEN GOTO 4120
4040 WKG=ACCN/BMF
4050 STA%=0
4060 GOSUB 10170
4070 IF ACTRAN>=DRAN AND ACTRAN <=1.05*DRAN THEN 4100 ELSE ICOUNT%=ICOUNT%+1
4080 R=DRAN*R/ACTRAN
4090 IF ICOUNT% >=30 THEN GOTO 4100 ELSE 4030
4100 LIMPRT%=0
4110 IF ACTRAN<DRAN OR ACTRAN >=1.05*DRAN THEN LIMPRT% = 1
4120 TAU=6.6/60 : LPD=CH(1)+CH(2)*LOG(TAU)+CH(3)*(LOG(TAU)^2)
4130 PD=EXP(LPD)
4140 BMF1=GRADE/PD
4150 IF BMF1>BMF THEN BMF=BMF1
4160 IF BMF1>BMF THEN BMFT$="GRADE" ELSE BMFT$="RANGE"
4170 IF TOR%=3 THEN BMF=BMFIN
4180 IF TOR%=3 THEN BMFT$="INPUT"
4190 IF PTOR%=3 AND TOR%=2 THEN BMF=BMF2
4200 IF PTOR%=3 AND TOR%=2 THEN BMFT$="INPUT"
4210 IF PTOR%=3 AND TOR%=2 THEN R=((BMF*100-B)/A)
4220 IF TOR%=3 THEN R=((BMF*100-B)/A)
4230 WKG = ACCN/BMF
4240 STA%=1
4250 GOSUB 10170
4260 IF ERRORF%=1 THEN 7220 ' END OF PROGRAM OPERATIONS
4270 GOSUB 13910 'COMPUTE WEIGHTS AND WEIGHT DEPENDENT VARIABLES.
4370 '
4380 REM PRINT AVSIZING OUTPUT REPORT
4390 '
4400 REM IF RF% = 1 THEN SKIP OUTPUT REPORT HEADER.
4410 '
4420 IF RF% =1 THEN 4490
4430 PRINT TAB(20)"AVSIZING OUTPUT REPORT"
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
4440 LPRINT TAB(29)"AVSIZING OUTPUT REPORT"
4450 X = CSRLIN
4460 LOCATE X,29:PRINT STRING$(22,196)
4470 X$=STRING$(22,95)
4480 LPRINT TAB(29);X$
4490 PRINT : LPRINT
4495 IF NUM%=1 THEN GOTO 4565
4500 TORCHECK=TOR%
4510 WHILE TORCHECK<>3
4520 NOCONV$=" WARNING! Iteration limit exeeded. THE RESULTS BELOW MAY NOT BE ME
ANINGFUL." : CONV$="Range converged in "
4530 IF LIMPRT%=1 THEN PRINT NOCONV$ ELSE PRINT CONV$;ICOUNT%;"iterations."
4540 IF LIMPRT%=1 THEN LPRINT NOCONV$ ELSE LPRINT CONV$;ICOUNT%;"iterations."
4550 TORCHECK=3
4560 WEND
4565 IF NUM%=1 THEN PRINT "Actual range not computed for AL-AIR."
4570 PRINT : LPRINT
4580 X=(80-LEN(TLE$))/2
4590 PRINT TAB(X)TLE$
4600 LPRINT TAB(X)TLE$
4610 PRINT : LPRINT
4620 F$="\                    \ \           \ "
4630 PRINT TAB(38);:PRINT TAB(50)"WT(KG)      VOL(LTR)    PWR(KW)"
4640 LPRINT TAB(38);:LPRINT TAB(50)"WT(KG)      VOL(LTR)    PWR(KW)"
4650 PRINT USING "& ## "; "THE VEHICLE CAPACITY IS ", CAP%
4660 LPRINT USING "& ## "; "THE VEHICLE CAPACITY IS ", CAP%
4670 PRINT USING F$; "THE VEHICLE TYPE IS ", VT$;:PRINT USING"&      ###.##";"
   MOTOR ",WMOT;:PRINT USING"       ###.##";VMOT,PEFPWR
4680 LPRINT USING F$; "THE VEHICLE TYPE IS ", VT$;:LPRINT USING"&      ###.##";"
     MOTOR ",WMOT;:LPRINT USING"      ###.##";VMOT,PEFPWR
4690 PRINT USING "& ###.##"; "THE DESIRED RANGE IS" ;DRAN;:PRINT " MI";:PRINT US
ING"&     ###.##";"        CONTR  ",WCON;:PRINT USING"      ###.##";VCT,CKW
4700 LPRINT USING "& ###.##"; "THE DESIRED RANGE IS" ;DRAN;:LPRINT " MI";:LPRINT
 USING"&     ###.##";"        CONTR  ",WCON;:LPRINT USING"        ###.##";VCT,CKW
4710 PRINT USING "\                       \ & "; "THE DOMINANT BMF IS", BMFT$;:PRINT U
SING"&     ###.##";"        EV TRANS ",WTF;:PRINT USING"      ###.##";VTT1F,ETKW

4720 LPRINT USING "\                       \ & "; "THE DOMINANT BMF IS", BMFT$;:LPRINT
 USING"&     ###.##";"        EV TRANS ",WTF;:LPRINT USING"      ###.##";VTT1F,E
TKW
4730 PRINT USING "\             \ \                   \ "; "THE BATTERY IS ", NAM$
;:PRINT USING"&     ####.##";" BATTR ",WB;:PRINT USING"      ###.##";BVOL,PB
4740 LPRINT USING "\            \ \                   \ "; "THE BATTERY IS ", NAM
$;:LPRINT USING"&     ####.##";" BATTR ",WB;:LPRINT USING"      ###.##";BVOL,PB
4750 PRINT TAB(34);:PRINT USING"&      ###.##";"ICE TRANS ",WTCVT;:PRINT USING"
    ###.##";GTRANVOL,EPOW
4760 LPRINT TAB(34);:LPRINT USING"&      ###.##";"ICE TRANS ",WTCVT;:LPRINT USING
"      ###.##";GTRANVOL,EPOW
4770 PRINT TAB(34);:PRINT USING"&      ###.##";"   ENGINE ",WHE;:PRINT USING"
  ###.##";ENGVOL,ENGKW
4780 LPRINT TAB(34);:LPRINT USING"&      ###.##";"   ENGINE ",WHE;:LPRINT USING"
     ###.##";ENGVOL,ENGKW
4790 PRINT : LPRINT
4800 PRINT USING "\                  \  #.###"; "THE BMF IS          ", BMF
4810 LPRINT USING "\                  \  #.###"; "THE BMF IS          ", BMF
4820 PRINT USING "\               \  ####.## "; "THE TEST WEIGHT IS   ", WT;:
PRINT"KG"
4830 LPRINT USING "\               \  ####.## "; "THE TEST WEIGHT IS   ", WT;
:LPRINT"KG"
4840 PRINT USING "\               \  ####.## "; "THE CURB WEIGHT IS    ", WC;
:PRINT "KG"
4850 LPRINT USING "\               \  ####.## "; "THE CURB WEIGHT IS    ", WC
;:LPRINT "KG"
```

```
4860 PRINT USING "\                              \  ###.##"; "THE ACTUAL RANGE IS    ", ACT
RAN!:PRINT " MI"
4870 LPRINT USING "\                              \  ###.##"; "THE ACTUAL RANGE IS    ", AC
TRAN!:LPRINT " MI"
4880 IF TORX=2 THEN 5100
4890 '
4900 REM MULTIPLE RUN LOGIC
4910 '
4920 PRINT
4930 LOCATE 22,41 : PRINT "DO YOU WISH TO MAKE ANOTHER RUN?" ;
4940  ANS$=INKEY$:IF ANS$<>"N"AND ANS$<>"n" AND ANS$<>"Y" AND ANS$<>"y" THEN GOT
O 4940
4950 IF ANS$="N" OR ANS$="n" THEN LOCATE 22,40:PRINT SPACE$(33):GOTO 4980
4960 IF ANS$="Y" OR ANS$="y" THEN RFX=1:LPRINT:CLS
4970 IF TORX=3 GOTO 320 ELSE GOTO 410
4980 PRINT "DO YOU WISH TO RUN ELVEC FOR THE VEHICLE SIZED IN THE LAST RUN(Y/N)?
" ;
4990  ANS1$=INKEY$:IF ANS1$<>"N"AND ANS1$<>"n"AND ANS1$<>"Y" AND ANS1$<>"y" THEN
 GOTO 4990
5000 IF ANS1$="N" OR ANS1$="n" GOTO 7260
5010 '
5020 REM INPUTS TO THE ELVEC PROGRAM.
5030 '
5040 IF VEHX=1 AND CAPX=2 THEN CDA=.51
5050 IF VEHX=1 AND CAPX=4 THEN CDA=.555
5060 IF VEHX=1 AND CAPX=5 THEN CDA=.6
5070 IF VEHX=1 AND CAPX=6 THEN CDA=1.18
5080 IF VEHX=2 AND CAPX=4 THEN CDA=.59
5090 IF VEHX=2 AND CAPX=5 THEN CDA=.64
5100 PTIRE=38!
5110 PKEFF=.95
5120 CRDIAL=1!
5130 PMXAML=2*PEFPWR
5140 U$(1)="URB1 1 " : U$(2)="URB2 1 " : U$(3)="URB3 1 " : U$(4)="URB4 1 "
5150 U$(5)="URB5 1 " : U$(6)="URB6 1 " : U$(7)="URB7 1 " : U$(8)="URB8 1 "
5160 U$(9)="URB9 1 " : U$(10)="URB10 1 " : U$(11)="URB11 1 " : U$(12)="URB12 1 "

5170 U$(13)="URB13 1 " : U$(14)="URB14 1 " : U$(15)="URB15 1 " : U$(16)="URB16 1
 "
5180 U$(17)="URB17 1 "
5190 CY$(1)=" - CYCLE 1" : CY$(2)=" - CYCLE 2" : CY$(3)=" - CYCLE 3"
5200 CY$(4)=" - CYCLE 4" : CY$(5)=" - CYCLE 5" : CY$(6)=" - CYCLE 6"
5210 CY$(7)=" - CYCLE 7" : CY$(8)=" - CYCLE 8" : CY$(9)=" - CYCLE 9"
5220 CY$(10)=" - CYCLE 10" : CY$(11)=" - CYCLE 11" : CY$(12)=" - CYCLE 12"
5230 '
5240 REM CONSTRUCT SOME COMMON CYCLE SEQUENCES
5250 '
5260 UC7.16$=U$(7)
5270 FOR I=8 TO 16
5280 UC7.16$=UC7.16$+U$(I)
5290 NEXT I
5300 UC3.11$=U$(3)
5310 FOR I=4 TO 11
5320 UC3.11$=UC3.11$+U$(I)
5330 NEXT I
5340 UC12.17$=U$(12)
5350 FOR I=13 TO 17
5360 UC12.17$=UC12.17$+U$(I)
5370 NEXT I
5380 UC3.8$=U$(3)
5390 FOR I=4 TO 8
5400 UC3.8$=UC3.8$+U$(I)
5410 NEXT I
```

```
5420 UC1.6$=U$(1)
5430 FOR I=2 TO 6
5440 UC1.6$=UC1.6$+U$(I)
5450 NEXT I
5460 PRINT
5470 PRINT
5480 IF TOR%=2 THEN 6260
5490 IF TOR%=3 THEN 5650
5495 '
5496 REM DETERMINE CYCLE (FEDERAL,HIGHWAY OR VAN)
5497 '
5550 CLS
5570 PRINT : PRINT
5580 PRINT "CYCLE TYPE NUMBER LIST"
5590 PRINT STRING$(22,196)
5600 PRINT "   1. FEDERAL CYCLE" : PRINT "   2. HIGHWAY CYCLE" : PRINT "   3. VA
N CYCLE"
5610 INPUT "   ENTER CYCLE TYPE NUMBER(1,2 OR 3)   " , CNUM%
5620 IF CNUM%<>1 AND CNUM%<>2 AND CNUM%<>3 THEN 5610
5650 '
5660 REM WRITE APPROPIATE CYCLE TO DISK.
5670 '
5680 OPEN "LOCAL.DAT" FOR OUTPUT AS #1
5690 GOSUB 7460 'CALL SUBROUTINE FRONT-END
5700 IF CNUM%=1 THEN PRINT#1, "NAMCYC FEDRAL"
5701 IF CNUM%=3 THEN GOSUB 7760 ' CALL SUBROUTINE PARAMVAR
5702 IF CNUM%=3 THEN GOSUB 9770 ' CALL SUBROUTINE CYCLE - VAN
5703 IF CNUM%=3 THEN PRINT#1, "END"
5704 IF CNUM%=2 THEN PRINT#1, "NAMCYC HIWAY"
5710 PRINT#1, "RUN"
5720 PRINT#1, "N"
5735 GOSUB 14250
5740 PRINT#1, "END"
5750 PRINT#1, TLE$
5760 PRINT#1, "N"
5770 PRINT#1, "QUIT"
5780 CLOSE #1
5790 PRINT : PRINT
5791 IF CNUM%=1 THEN FFF$="FEDERAL"
5792 IF CNUM%=2 THEN FFF$="HIGHWAY"
5793 IF CNUM%=3 THEN FFF$="VAN"
5800 PRINT "AN INPUT FILE HAS BEEN WRITTEN TO DISK USING THE "+FFF$+" CYCLE AND
DATA FROM THE LAST RUN."
5810 IF TOR%=3 THEN PRINT "THE REDESIGN OPTION HAS BEEN USED TO CREATE THIS FILE
."
5820 PRINT : PRINT
5830 WHILE DOB%=1
5840 PRINT "YOU WISH TO RUN THE "+FFF$+" CYCLE IN DEMAND THEREFORE:" : PRINT "
 THE LOCAL FILE IS LOCAL.DAT" : PRINT "   THE REMOTE FILE IS STAREL.COM"
5850 PRINT "   THE RUN COMMAND FILE IS @MAX "
5860 PRINT "   (RESPOND TO THE FIRST TWO PROMPTS FROM THE KEYBOARD)
5870 DOB%=0 : WEND
5880 WHILE DOB%=2
5890 PRINT "YOU WISH TO RUN THE "+FFF$+" CYCLE IN BATCH THEREFORE:" : PRINT "
THE LOCAL FILE IS LOCAL.DAT" : PRINT "   THE REMOTE FILE IS STAREL.COM"
5900 PRINT "   THE SUBMIT COMMAND FILE IS @GO"
5910 DOB%=0 : WEND
5920 IF TOR%<>2 THEN GOSUB 9900 'WRITE TO THE VEHICLE.DAT FILE
5930 GOTO 7260
6230 '
6240 REM WRITE 24 HR. CYCLE TO DISK.
6250 '
6260 OPEN NAM24$+".DAT" FOR OUTPUT AS #1
```

```
6270 IF CAP%=6 THEN 6830
6280 GOSUB 7460 'CALL SUBROUTINE FRONT-END
6290 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6300 GOSUB 7850 'CALL SUBROUTINE CYCLE - 1
6310 PRINT#1, TLE$+CY$(1)
6320 PRINT#1, "N"
6330 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6340 GOSUB 8000 'CALL SUBROUTINE CYCLE - 2
6350 PRINT#1, TLE$+CY$(2)
6360 PRINT#1, "N"
6370 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6380 GOSUB 8130 'CALL SUBROUTINE CYCLE - 3
6390 PRINT#1, TLE$+CY$(3)
6400 PRINT#1, "N"
6410 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6420 GOSUB 8310 'CALL SUBROUTINE CYCLE - 4
6430 PRINT#1, TLE$+BAT$+CY$(4)
6440 PRINT#1, "N"
6450 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6460 GOSUB 8450 'CALL SUBROUTINE CYCLE - 5
6470 PRINT#1, TLE$+CY$(5)
6480 PRINT#1, "N"
6490 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6500 GOSUB 8620 'CALL SUBROUTINE CYCLE - 6
6510 PRINT#1, TLE$+CY$(6)
6520 PRINT#1, "N"
6530 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6540 GOSUB 8820 'CALL SUBROUTINE CYCLE - 7
6550 PRINT#1, TLE$+CY$(7)
6560 PRINT#1, "N"
6570 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6580 GOSUB 9000 'CALL SUBROUTINE CYCLE - 8
6590 PRINT#1, TLE$+CY$(8)
6600 PRINT#1, "N"
6605 IF VEH%=2 THEN GOSUB 14110 'CALL HYBRID SUBROUTINE
6610 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6620 GOSUB 9190 'CALL SUBROUTINE CYCLE - 9
6630 PRINT#1, TLE$+CY$(9)
6640 PRINT#1, "N"
6650 IF CYCLE%=9 THEN 7040
6660 REM CYCLE 10
6670 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6680 GOSUB 9350 'CALL SUBROUTINE CYCLE - 10
6690 PRINT#1, TLE$+CY$(10)
6700 PRINT#1, "N"
6710 IF CYCLE%=10 THEN 7040
6720 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6730 GOSUB 9490 'CALL SUBROUTINE CYCLE - 11
6740 PRINT#1, TLE$+CY$(11)
6750 PRINT#1, "N"
6760 IF CYCLE%=11 THEN 7040
6770 REM CYCLE 12
6780 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6790 GOSUB 9630 'CALL SUBROUTINE CYCLE - 12
6800 PRINT#1, TLE$+CY$(12)
6810 PRINT#1, "N"
6820 IF CYCLE%=12 THEN 7040
6830 REM BEGIN VAN CYCLES
6840 IF CAP%<>6 THEN 7040
6845 GOSUB 7460 'CALL SUBROUTINE FRONT-END
6850 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6860 GOSUB 9770 'CALL SUBROUTINE CYCLE - VAN
6862 PRINT#1, "mark 10.5hr"
```

```
6863 PRINT#1, "END"
6864 PRINT#1, "RUN"
6870 PRINT#1, "N"
6880 GOSUB 14250
6881 IF VEH%=2 THEN GOSUB 14110 'CALL HYBRID SUBROUTINE
6890 PRINT#1, "END"
6900 PRINT#1, TLE$+CY$(1)
6910 PRINT#1, "N"
6920 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6930 GOSUB 9770 'CALL SUBROUTINE CYCLE - VAN
6933 PRINT#1, "park 2.5hr"
6934 PRINT#1, "END"
6935 PRINT#1, "RUN"
6940 PRINT#1, TLE$+CY$(2)
6950 PRINT#1, "N"
6960 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
6970 GOSUB 9770 'CALL SUBROUTINE CYCLE - VAN
6974 PRINT#1, "park 1.5hr"
6975 PRINT#1, "END"
6976 PRINT#1, "RUN"
6980 PRINT#1, TLE$+CY$(3)
6990 PRINT#1, "N"
7000 GOSUB 7760 'CALL SUBROUTINE PARAMVAR
7010 GOSUB 9770 'CALL SUBROUTINE CYCLE - VAN
7015 PRINT#1, "park 0.9hr"
7016 PRINT#1, "END"
7017 PRINT#1, "RUN"
7020 PRINT#1, TLE$+CY$(4)
7030 PRINT#1, "N"
7040 REM END 24 HR. CYCLE STATEMENTS
7050 PRINT#1, "QUIT"
7060 CLOSE #1
7070 PRINT : PRINT
7080 PRINT "AN INPUT FILE HAS BEEN WRITTEN TO DISK USING THE 24 HOUR CYCLE AND D
ATA FROM THE LAST RUN FOR WHICH A FEDRAL, HIGHWAY, OR VAN INPUT FILE WAS CREATED
"
7090 PRINT : PRINT
7100 WHILE DOB%=1
7110 PRINT "YOU WISH TO RUN THE 24 HR. CYCLE IN DEMAND THEREFORE:" : PRINT "   T
HE LOCAL FILE IS STAREL.DAT" : PRINT "   THE REMOTE FILE IS STAREL.COM"
7120 PRINT "   THE RUN COMMAND FILE IS @MAX "
7130 PRINT "   (RESPOND TO THE FIRST TWO PROMPTS FROM THE KEYBOARD)
7150 DOB%=0
7160 WEND
7170 PRINT : PRINT
7180 WHILE DOB%=2
7190 PRINT "YOU WISH TO RUN THE 24 HR. CYCLE IN BATCH THEREFORE:" : PRINT "   TH
E LOCAL FILE IS "+NAM24$+".DAT" : PRINT "   THE REMOTE FILE IS "+NAM24$+".COM"
7200 PRINT "   THE SUBMIT COMMAND IS SUBMIT "+NAM24$+".COM/NOPRINT/QUE=FIFO"
7210 DOB%=0 : WEND
7220 PRINT : PRINT : PRINT : PRINT : PRINT
7225 '
7226 REM OPEN FILES OF THE FORM XXX.COS AND XXX.ENG
7227 '
7230 OPEN NAM24$+".COS" FOR OUTPUT AS #3
7232 WRITE #3, PEFPWR:CKW:ETKW:EPOW:NAM$:WC
7237 CLOSE #3
7240 OPEN NAM24$+".ENG" FOR OUTPUT AS #3
7242 WRITE #3, WB:WT:TLE$:VEH%
7250 CLOSE #3
7251 '
7252 REM DISPLAY WARNINGS OR ERROR MESSAGES (IF REQUIRED) BEFORE ENDING PROGRAM
OPERATIONS.
```

```
7253 '
7260 PRINT : PRINT : PRINT
7270 PRINT : LPRINT
7280 IF ERRORFX=1 THEN PRINT "SPECIFIC POWER IS OUT OF RANGE."
7290 IF ERRORFX=1 THEN LPRINT "SPECIFIC POWER IS OUT OF RANGE."
7300 IF ERRORFX=1 AND LIMPRTX=1 THEN PRINT "WARNING! The Iteration limit in the
Actual Range calculation was exceeded.  Therefore the Actual Range may not have
converged."
7310 IF ERRORFX=1 AND LIMPRTX=1 THEN LPRINT "WARNING! The Iteration limit in the
 Actual Range calculation was exceeded.  Therefore the Actual Range may not have
 converged."
7320 IF ERRORFX=1 AND LIMPRTX=1 THEN PRINT "   The current value is";ACTRAN
7330 IF ERRORFX=1 AND LIMPRTX=1 THEN LPRINT "   The current value is";ACTRAN
7340 '
7350 REM END OF PROGRAM OPERATIONS
7360 '
7370 LOCATE 23,1 : PRINT SPACE$(75)
7380 LOCATE 23,25:PRINT"** END OF PROGRAM OPERATIONS **"
7390 LPRINT TAB(25)"**END OF PROGRAM OPERATIONS**"
7400 LPRINT CHR$(12)
7410 '
7420 REM RESTART OPTION
7430 '
7440 LOCATE 25,30:PRINT"TYPE RUN TO RE-START"
7450 END
7460 '*********************************************************************
7470 '
7480 REM  SUBROUTINE FRONT-END.
7490 '
7500 '*********************************************************************
7510 IF TORX=1 OR TORX=3 THEN PRINT#1, "CREATE/LOG STAREL.COM"
7520 IF TORX=2 THEN PRINT#1, "CREATE/LOG "+NAM24$+".COM"
7530 IF DOBX=1 THEN 7570
7540 PRINT#1, "$@SIAO:[GRCUSER.STORE]RUNELVEC"
7550 PRINT#1, "N"
7560 PRINT#1, ""
7570 PRINT#1, "E"
7580 PRINT#1, "N"
7590 PRINT#1, "N"
7600 PRINT#1, "N"
7610 PRINT#1, "USERDATA"
7620 PRINT#1, "ADVEV"
7622 PRINT#1, "MDLMOT ANALYT"
7625 IF NUMX<>1 THEN PRINT#1, "MDLBAT ACTRNG"
7630 PRINT#1, "NAMBAT ";NAM$
7750 RETURN
7760 ' ********************************************************************
7770 '
7780 REM SUBROUTINE PARAMVAR
7790 '
7800 ' ********************************************************************
7810 PRINT#1, "PARAMVAR"
7820 PRINT#1, "NAMCYC"
7830 PRINT#1, "N"
7840 RETURN
7850 ' ********************************************************************
7860 '
7870 REM SUBROUTINE CYCLE - 1
7880 '
7890 ' ********************************************************************
7900 PRINT#1, U$(1)+U$(2)
7910 PRINT#1, "park 1.9hr"
7920 PRINT#1, U$(3 [illegible]
```

```
7930 PRINT#1, "park 21.90hr"
7940 PRINT#1, "END"
7950 PRINT#1,"RUN"
7960 PRINT#1, "N"
7975 GOSUB 14250
7980 PRINT#1, "END"
7990 RETURN
8000 ' ************************************************************************
8010 '
8020 REM SUBROUTINE CYCLE - 2
8030 '
8040 ' ************************************************************************
8050 PRINT#1, UC1.6@
8060 PRINT#1, "park 5.01hr"
8070 PRINT#1, UC7.16@
8080 PRINT#1, U@(17)
8090 PRINT#1, "park 18.60hr"
8100 PRINT#1, "END"
8110 PRINT#1, "RUN"
8120 RETURN
8130 ' ************************************************************************
8140 '
8150  REM SUBROUTINE CYCLE - 3
8160 '
8170 ' ************************************************************************
8180 PRINT#1, U@(1)
8190 PRINT#1, "park 5.16hr"
8200 PRINT#1, U@(2)+U@(3)+U@(4)+U@(5)+U@(6)
8210 PRINT#1, "park 0.75hr"
8220 PRINT#1, UC7.16@
8230 PRINT#1, U@(17)
8240 PRINT#1, "park 2.77hr"
8250 PRINT#1, UC1.6@
8260 PRINT#1, U@(7)+U@(8)+U@(9)
8270 PRINT#1, "park 14.73hr"
8280 PRINT#1, "END"
8290 PRINT#1, "RUN"
8300 RETURN
8310 ' ************************************************************************
8320 '
8330 REM SUBROUTINE CYCLE - 4
8340 '
8350 ' ************************************************************************
8360 PRINT#1, "fedral 1"
8370 PRINT#1, "park 0.95hr"
8380 PRINT#1, U@(2)
8390 PRINT#1, "park 3.44hr"
8400 PRINT#1, "fedral 1"
8410 PRINT#1, "park 18.79hr"
8420 PRINT#1, "END"
8430 PRINT#1, "RUN"
8440 RETURN
8450 ' ************************************************************************
8460 '
8470 REM SUBROUTINE CYCLE - 5
8480 '
8490 ' ************************************************************************
8500 PRINT#1, UC1.6@
8510 PRINT#1, "park 7.15hr"
8520 PRINT#1, UC7.16@
8530 PRINT#1, U@(17)
8540 PRINT#1, "park 1.56hr"
8550 PRINT#1, "fedral 1"
```

```
8560 PRINT#1, "park 6.87hr"
8570 PRINT#1, "fedral 1"
8580 PRINT#1, "park 7.28hr"
8590 PRINT#1, "END"
8600 PRINT#1, "RUN"
8610 RETURN
8620 '*********************************************************************
8630 '
8640 REM SUBROUTINE CYCLE - 6
8650 '
8660 ' ********************************************************************
8670 PRINT#1, "fedral 2"
8680 PRINT#1, "park 1.04hr"
8690 PRINT#1, UC1.60
8700 PRINT#1, U$(7)+U$(8)+U$(9)
8710 PRINT#1, "park 0.87hr"
8720 PRINT#1, U$(1)+U$(2)
8730 PRINT#1, "park 6.83hr"
8740 PRINT#1, UC3.110
8750 PRINT#1, UC12.170
8760 PRINT#1, "park 1.63hr"
8770 PRINT#1, "fedral 1"
8780 PRINT#1, "park 11.89hr"
8790 PRINT#1, "END"
8800 PRINT#1, "RUN"
8810 RETURN
8820 '*********************************************************************
8830 '
8840 REM SUBROUTINE CYCLE - 7
8850 '
8860 '*********************************************************************
8870 PRINT#1, "fedral 2"
8880 PRINT#1, "park 4.57hr"
8890 PRINT#1, U$(1)
8900 PRINT#1, "park 0.60hr"
8910 PRINT#1, "fedral 2"
8920 PRINT#1, "park 2.57hr"
8930 PRINT#1, "fedral 1"
8940 PRINT#1, "park 1.38hr"
8950 PRINT#1, "fedral 1"
8960 PRINT#1, "park 12.55hr"
8970 PRINT#1, "END"
8980 PRINT#1, "RUN"
8990 RETURN
9000 '*********************************************************************
9010 '
9020 REM SUBROUTINE CYCLE - 8
9030 '
9040 '*********************************************************************
9050 PRINT#1, "fedral 2"
9060 PRINT#1, "park 0.82hr"
9070 PRINT#1, "fedral 2"
9080 PRINT#1, "park 0.15hr"
9090 PRINT#1, "fedral 2"
9100 PRINT#1, "park 3.73hr"
9110 PRINT#1, U$(1)+U$(2)
9120 PRINT#1, "park 0.216hr"
9130 PRINT#1, UC3.110
9140 PRINT#1, UC12.170
9150 PRINT#1, "park 16.42hr"
9160 PRINT#1, "END"
9170 PRINT#1, "RUN"
```

```
9190 '**********************************************************************
9200 '
9210 REM SUBROUTINE CYCLE - 9
9220 '
9230 '**********************************************************************
9240 PRINT#1, "hiway 4"
9250 PRINT#1, "park 7.04hr"
9260 PRINT#1, "fedral 1"
9270 PRINT#1, "hiway 1"
9280 PRINT#1, "fedral 1"
9290 PRINT#1, "park 0.66hr"
9300 PRINT#1, "fedral 1"
9310 PRINT#1, "park 14.09hr"
9320 PRINT#1, "END"
9330 PRINT#1, "RUN"
9340 RETURN
9350 '**********************************************************************
9360 '
9370 REM SUBROUTINE CYCLE - 10
9380 '
9390 '**********************************************************************
9400 PRINT#1, "hiway 4"
9410 PRINT#1, "park 6.5hr"
9420 PRINT#1, "fedral 1"
9430 PRINT#1, "hiway 4"
9440 PRINT#1, "fedral 1"
9450 PRINT#1, "park 15.04hr"
9460 PRINT#1, "END"
9470 PRINT#1, "RUN"
9480 RETURN
9490 '**********************************************************************
9500 '
9510 REM SUBROUTINE CYCLE - 11
9520 '
9530 '**********************************************************************
9540 PRINT#1, "hiway 15"
9550 PRINT#1, "park 2.61hr"
9560 PRINT#1, U$(1)+U$(2)
9570 PRINT#1, "park 0.57hr"
9580 PRINT#1, UC3.8$+U$(9)
9590 PRINT#1, "park 17.42hr"
9600 PRINT#1, "END"
9610 PRINT#1, "RUN"
9620 RETURN
9630 '**********************************************************************
9640 '
9650 REM SUBROUTINE CYCLE - 12
9660 '
9670 '**********************************************************************
9680 PRINT#1, "fedral 1"
9690 PRINT#1, "hiway 16"
9700 PRINT#1, "park 1.0hr"
9710 PRINT#1, "hiway 7"
9720 PRINT#1, "fedral 1"
9730 PRINT#1, "park 17.35hr"
9740 PRINT#1, "END"
9750 PRINT#1, "RUN"
9760 RETURN
9770 '**********************************************************************
9780 '
9790 REM SUBROUTINE CYCLE - VAN
9800 '
9810 '**********************************************************************
```

```
9820 PRINT#1, U0(1)+UC3.110
9830 PRINT#1, UC12.170
9840 PRINT#1, "park 1.5hr"
9850 PRINT#1, U0(1)+UC3.110
9860 PRINT#1, UC12.170
9890 RETURN
9900 '*****************************************************************
9910 '
9920 REM SUBROUTINE VEHICLE - DATA
9930 '
9940 '*****************************************************************
9950 OPEN "VEHICLE.DAT" FOR OUTPUT AS #2
9960 WRITE #2, TLE0, CAPX, VEHX, ICWT, DRAN, NUM%, SNUM%, CDA, CNUM%, BMF1, BMF,
TOR%
9970 CLOSE #2
9980 RETURN
9990 '*****************************************************************
10000 '
10010 REM SUBROUTINE CH - READ
10020 '
10030 '*****************************************************************
10040 FOR I=1 TO 3
10050 READ CH(I)
10060 NEXT I
10070 RETUHN
10080 '*****************************************************************
10090 '
10100 REM SUBROUTINE BATN$- READ
10110 '
10120 '*****************************************************************
10130 FOR I=1 TO 4
10140 READ BATN$(I)
10150 NEXT I
10160 RETURN
10170 '*****************************************************************

10180 '
10190 REM SUBROUTINE ACTUAL - RANGE
10200 '
10210 '*****************************************************************

10220 ERRORF=0
10230 IF NUM% = 1 THEN 10360  'BRANCH TO AL-AIR DATA SET
10240 IF NUM% = 2 THEN 10450  'BRANCH TO FE-AIR DATA SET
10250 IF NUM% = 3 THEN 10820  'BRANCH TO LI-FE-S DATA SET
10260 IF NUM% = 4 THEN 11190  'BRANCH TO LI-FE-S2 DATA SET
10270 IF NUM% = 5 THEN 11280  'BRANCH TO NA-S DATA SET
10280 IF NUM% = 6 THEN 11650  'BRANCH TO NI-FE DATA SET
10290 IF NUM% = 7 THEN 12020  'BRANCH TO NI-ZN DATA SET
10300 IF NUM% = 8 THEN 12110  'BRANCH TO PB-ACID DATA SET
10310 IF NUM% = 9 THEN 12480  'BRANCH TO PB-ACID/BP DATA SET
10320 IF NUM% = 10 THEN 12850  'BRANCH TO ZN-BR2 DATA SET
10330 IF NUM% = 11 THEN 13220  'BRANCH TO ZN-CL2 DATA SET
10340 '
10350 REM DATA TAKEN FROM SPECIFIC POWER X DOD CHARTS FOR THE ELEVEN BATTERY TYP
ES
10360 'AL-AIR DATA SET
10370 N=2
10380 DATA 0,157
10390 DATA 100,90
10400 RESTORE 10380
10410 GOSUB 13620
10420 RESTORE 10380
```

```
10430 GOSUB 13690
10440 GOTO 13760
10450 ' FE-AIR DATA SET
10460 IF SNUM%=1 THEN 10500
10470 IF SNUM%=2 THEN 10580
10480 IF SNUM%=3 THEN 10660
10490 IF SNUM%=4 THEN 10740
10500 N = 5 :  ' P/E=1.0
10510 DATA 0,102,107,110,112
10520 DATA 100,90,70,50,40
10530 RESTORE 10510
10540 GOSUB 13620
10550 RESTORE 10520
10560 GOSUB 13690
10570 GOTO 13760
10580 N = 6 :  ' P/E=2.1
10590 DATA 0,115,125,131,140,143
10600 DATA 100,90,80,70,50,40
10610 RESTORE 10590
10620 GOSUB 13620
10630 RESTORE 10600
10640 GOSUB 13690
10650 GOTO 13760
10660 N = 6 :  ' P/E=2.4
10670 DATA 0,136,145,150,157,159
10680 DATA 100,90,78,70,50,40
10690 RESTORE 10670
10700 GOSUB 13620
10710 RESTORE 10680
10720 GOSUB 13690
10730 GOTO 13760
10740 N = 6 :  ' P/E=3.3
10750 DATA 0,146,156,162,165,167
10760 DATA 100,90,80,70,50,40
10770 RESTORE 10750
10780 GOSUB 13620
10790 RESTORE 10760
10800 GOSUB 13690
10810 GOTO 13760
10820 'LI-FE-S DATA SET
10830 IF SNUM%=1 THEN 10870
10840 IF SNUM%=2 THEN 10950
10850 IF SNUM%=3 THEN 11030
10860 IF SNUM%=4 THEN 11110
10870 N = 5 :  'P/E=1.0
10880 DATA 0,98,126,161,177
10890 DATA 100,90,70,50,40
10900 RESTORE 10880
10910 GOSUB 13620
10920 RESTORE 10890
10930 GOSUB 13690
10940 GOTO 13760
10950 N = 6 : 'P/E=2.1
10960 DATA 0,90,110,140,165,172
10970 DATA 100,90,85,70,50,40
10980 RESTORE 10960
10990 GOSUB 13620
11000 RESTORE 10970
11010 GOSUB 13690
11020 GOTO 13760
11030 N = 6 :   'P/E=2.4
11040 DATA 0,90,110,140,165,172
11050 DATA 100,90,85,70,50,40
```

```
11060 RESTORE 11040
11070 GOSUB 13620
11080 RESTORE 11050
11090 GOSUB 13690
11100 GOTO 13760
11110 N = 5 :   'P/E=3.3
11120 DATA 0,107,137,175,198
11130 DATA 100,90,70,50,40
11140 RESTORE 11120
11150 GOSUB 13620
11160 RESTORE 11130
11170 GOSUB 13690
11180 GOTO 13760
11190 ' LI-FE-S2 DATA SET
11200 N = 5 : MAT$ = "          "
11210 DATA 0.0,110.0,142.5,165.0,180.0
11220 DATA 100.0,90.0,80.0,66.0,50.0
11230 RESTORE 11210
11240 GOSUB 13620
11250 RESTORE 11220
11260 GOSUB 13690
11270 GOTO 13760
11280 ' NA-S DATA SET
11290 IF SNUMX=1 THEN 11330
11300 IF SNUMX=2 THEN 11410
11310 IF SNUMX=3 THEN 11490
11320 IF SNUMX=4 THEN 11570
11330 N = 6 :   ' P/E=1.0
11340 DATA 0,129,135,141,148,150
11350 DATA 100,90,80,70,50,40
11360 RESTORE 11340
11370 GOSUB 13620
11380 RESTORE 11350
11390 GOSUB 13690
11400 GOTO 13760
11410 N = 5 :   ' P/E=2.1
11420 DATA 0,180,192,199,200
11430 DATA 100,90,70,50,40
11440 RESTORE 11420
11450 GOSUB 13620
11460 RESTORE 11430
11470 GOSUB 13690
11480 GOTO 13760
11490 N = 5 :   ' P/E=2.4
11500 DATA 0,180,210,224,228
11510 DATA 100,90,70,50,40
11520 RESTORE 11500
11530 GOSUB 13620
11540 RESTORE 11510
11550 GOSUB 13690
11560 GOTO 13760
11570 N = 5 :   ' P/E=3.3
11580 DATA 0,220,234,244,246
11590 DATA 100,90,70,50,40
11600 RESTORE 11580
11610 GOSUB 13620
11620 RESTORE 11590
11630 GOSUB 13690
11640 GOTO 13760
11650 ' NI-FE DATA SET
11660 IF SNUMX=1 THEN 11700
11670 IF SNUMX=2 THEN 11780
[illegible]
```

```
11690 IF SNUMX=4 THEN 11940
11700 N = 6 :  ' P/E=1.0
11710 DATA 0,45,75,105,120,124
11720 DATA 100,97,90,70,50,40
11730 RESTORE 11710
11740 GOSUB 13620
11750 RESTORE 11720
11760 GOSUB 13690
11770 GOTO 13760
11780 N = 6 :  ' P/E=2.1
11790 DATA 0,75,90,120,141,150
11800 DATA 100,95,90,70,50,40
11810 RESTORE 11790
11820 GOSUB 13620
11830 RESTORE 11800
11840 GOSUB 13690
11850 GOTO 13760
11860 N = 6 :  ' P/E=2.1
11870 DATA 0,75,90,120,141,150
11880 DATA 100,95,90,70,50,40
11890 RESTORE 11870
11900 GOSUB 13620
11910 RESTORE 11880
11920 GOSUB 13690
11930 GOTO 13760
11940 N = 6 :  ' P/E=3.3
11950 DATA 0,90,110,140,160,165
11960 DATA 100,97,90,70,50,40
11970 RESTORE 11950
11980 GOSUB 13620
11990 RESTORE 11960
12000 GOSUB 13690
12010 GOTO 13760
12020 'NI-ZN DATA SET
12030 N = 8
12040 DATA 0.0,110.0,140.0,160.0,170.0,180.0,195.0,199.0
12050 DATA 100.0,92.2,88.0,82.5,78.5,72.7,58.0,50.0
12060 RESTORE 12040
12070 GOSUB 13620
12080 RESTORE 12050
12090 GOSUB 13690
12100 GOTO 13760
12110 ' PB-ACID DATA SET
12120 IF SNUMX=1 THEN 12160
12130 IF SNUMX=2 THEN 12240
12140 IF SNUMX=3 THEN 12320
12150 IF SNUMX=4 THEN 12400
12160 N = 7 :  ' P/E=1.0
12170 DATA 0,50,80,93,105,120,124
12180 DATA 100,98,90,82,70,50,40
12190 RESTORE 12170
12200 GOSUB 13620
12210 RESTORE 12180
12220 GOSUB 13690
12230 GOTO 13760
12240 N = 6 :  ' P/E=2.1
12250 DATA 0,70,90,115,135,145
12260 DATA 100,98,90,70,50,40
12270 RESTORE 12250
12280 GOSUB 13620
12290 RESTORE 12260
12300 GOSUB 13690
12310 GOTO 13760
```

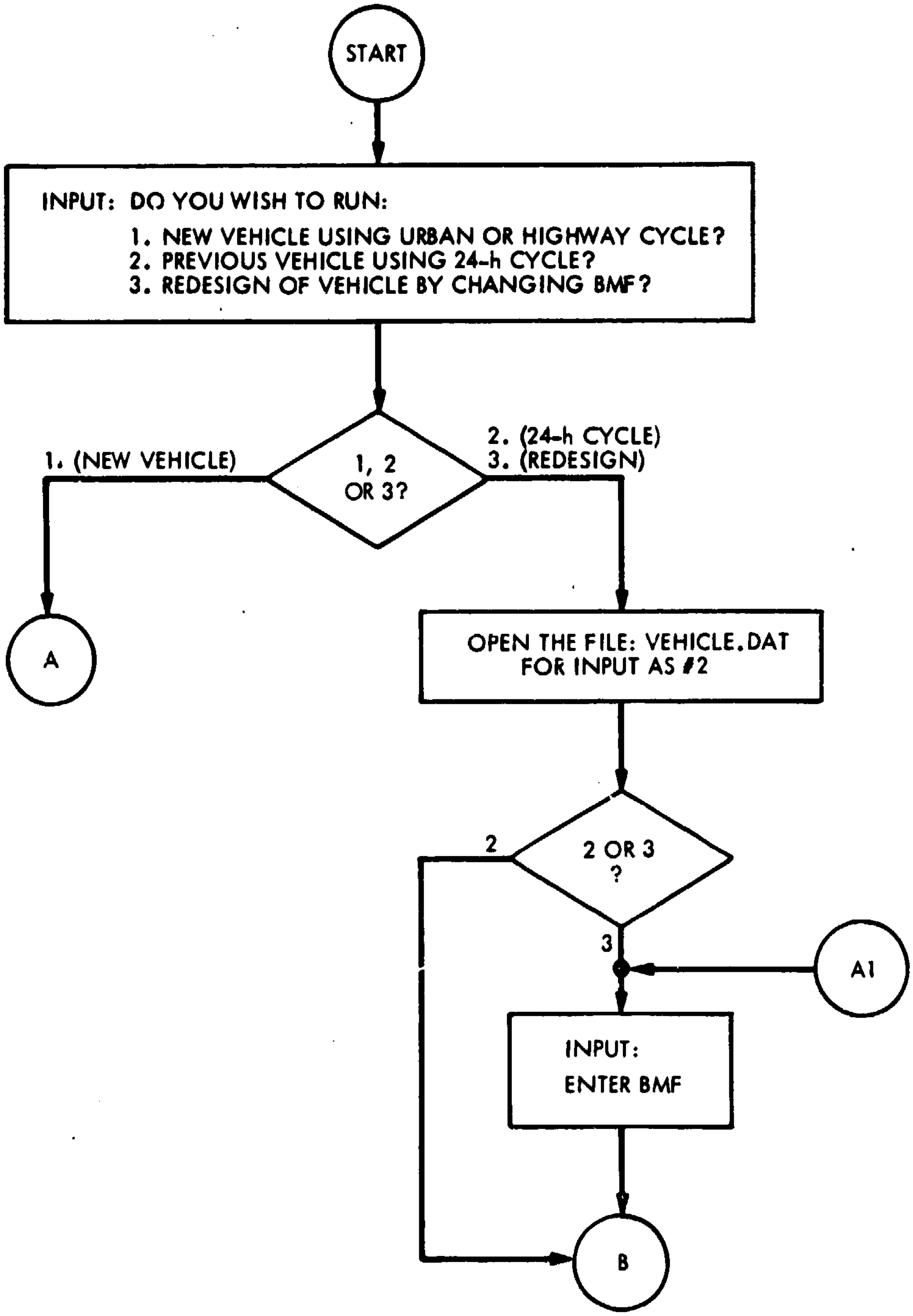
```
12320 N = 6 :  ' P/E=2.4
12330 DATA 0,70,90,115,135,145
12340 DATA 100,98,90,70,50,40
12350 RESTORE 12330
12360 GOSUB 13620
12370 RESTORE 12340
12380 GOSUB 13690
12390 GOTO 13760
12400 N = 6 :  ' P/E=3.3
12410 DATA 0,85,100,125,145,155
12420 DATA 100,97,90,70,50,40
12430 RESTORE 12410
12440 GOSUB 13620
12450 RESTORE 12420
12460 GOSUB 13690
12470 GOTO 13760
12480 ' PB-ACID/BP DATA SET
12490 IF SNUM%=1 THEN 12530
12500 IF SNUM%=2 THEN 12610
12510 IF SNUM%=3 THEN 12690
12520 IF SNUM%=4 THEN 12770
12530 N = 5 :  ' P/E=1.0
12540 DATA 0,275,345,400,426
12550 DATA 100,90,70,50,40
12560 RESTORE 12540
12570 GOSUB 13620
12580 RESTORE 12550
12590 GOSUB 13690
12600 GOTO 13760
12610 N = 5 :  ' P/E=1.0
12620 DATA 0,275,345,400,426
12630 DATA 100,90,70,50,40
12640 RESTORE 12620
12650 GOSUB 13620
12660 RESTORE 12630
12670 GOSUB 13690
12680 GOTO 13760
12690 N = 5 :  ' P/E=1.0
12700 DATA 0,275,345,400,426
12710 DATA 100,90,70,50,40
12720 RESTORE 12700
12730 GOSUB 13620
12740 RESTORE 12710
12750 GOSUB 13690
12760 GOTO 13760
12770 N = 5 :  ' P/E=1.0
12780 DATA 0,275,345,400,426
12790 DATA 100,90,70,50,40
12800 RESTORE 12780
12810 GOSUB 13620
12820 RESTORE 12790
12830 GOSUB 13690
12840 GOTO 13760
12850 ' ZN-BR2 DATA SET
12860 IF SNUM%=1 THEN 12900
12870 IF SNUM%=2 THEN 12980
12880 IF SNUM%=3 THEN 13060
12890 IF SNUM%=4 THEN 13140
12900 N = 6 :  'P/E=1.0
12910 DATA 0,35,52,69,83,89
12920 DATA 100,97,90,70,50,40
12930 RESTORE 12910
12940 GOSUB 13620
```

```
12950 RESTORE 12920
12960 GOSUB 13690
12970 GOTO 13760
12980 N = 6 :  'P/E=2.1
12990 DATA 0,55,72,96,115,125
13000 DATA 100,97,90,70,50,40
13010 RESTORE 12990
13020 GOSUB 13620
13030 RESTORE 13000
13040 GOSUB 13690
13050 GOTO 13760
13060 N = 6 :  'P/E=2.4
13070 DATA 0,65,85,113,135,147
13080 DATA 100,98,90,70,50,40
13090 RESTORE 13070
13100 GOSUB 13620
13110 RESTORE 13080
13120 GOSUB 13690
13130 GOTO 13760
13140 N = 6 :  'P/E=3.3
13150 DATA 0,85,94,125,150,160
13160 DATA 100,95,90,70,50,40
13170 RESTORE 13150
13180 GOSUB 13620
13190 RESTORE 13160
13200 GOSUB 13690
13210 GOTO 13760
13220 ' ZN-CL2 DATA SET
13230 IF SNUM%=1 THEN 13270
13240 IF SNUM%=2 THEN 13350
13250 IF SNUM%=3 THEN 13430
13260 IF SNUM%=4 THEN 13510
13270 N = 5 :  'P/E=1.0
13280 DATA 0,80,84,86,87
13290 DATA 100,90,70,50,40
13300 RESTORE 13280
13310 GOSUB 13620
13320 RESTORE 13290
13330 GOSUB 13690
13340 GOTO 13760
13350 N = 6 :  'P/E=2.1
13360 DATA 0,90,96,103,110,114
13370 DATA 100,90,82,70,30,40
13380 RESTORE 13360
13390 GOSUB 13620
13400 RESTORE 13370
13410 GOSUB 13690
13420 GOTO 13760
13430 N = 6 :  'P/E=2.4
13440 DATA 0,110,116,121,127,131
13450 DATA 100,90,81,70,50,40
13460 RESTORE 13440
13470 GOSUB 13620
13480 RESTORE 13450
13490 GOSUB 13690
13500 GOTO 13760
13510 N = 6 :  'P/E=3.3
13520 DATA 0,115,121,128,130,131
13530 DATA 100,90,85,70,50,40
13540 RESTORE 13520
13550 GOSUB 13620
13560 RESTORE 13530
13570 GOSUB 13690
```

```
13580 GOTO 13760
13590 '
13600 REM SUBROUTINE FOR READING THE SPECIFIC POWER DATA INTO THE D(I) ARRAY.
13610 '
13620 FOR I = 1 TO N
13630 READ DOM(I)
13640 NEXT I
13650 RETURN
13660 '
13670 REM SUBROUTINE FOR READING THE DOD DATA INTO THE R(I) ARRAY.
13680 '
13690 FOR I = 1 TO N
13700 READ RAN(I)
13710 NEXT I
13720 RETURN
13730 '
13740 REM BRANCH TO ERROR MESSAGE AND EXIT IF SPECIFIC POWER IS OUT OF RANGE.
13750 '
13760 IF STA%=1 THEN IF WKG < 0 OR WKG > DOM(N) THEN ERRORF%=1
13770 IF STA%=1 THEN IF WKG < 0 OR WKG > DOM(N) THEN 13890
13780 '
13790 REM INTERPOLATION ALGORITHM.
13800 '
13810 FOR I = 1 TO N-1
13820 IF WKG < DOM(I+1) AND WKG > =DOM(I) THEN 13840
13830 NEXT I
13840 DOD = ((RAN(I+1)-RAN(I))/(DOM(I+1)-DOM(I)))*(WKG-DOM(I)) + RAN(I)
13850 '
13860 REM COMPUTE ACTUAL RANGE.
13870 '
13880 ACTRAN = DOD*R/100
13890 RETURN
13900 RETURN
13910 '*************************************************************************
13920 '
13930 REM SUBROUTINE WEIGHT
13940 '
13950 '*************************************************************************
13960 WTERM1= WSH+PANDPL : WTERM2=BMF+WMOT1+WCON1+WTR1+WHE1
13970 WT=WTERM1/(1-(1.3*WTERM2))
13980 WB=BMF*WT : PACC=ACC*WB
13990 WC=WT-PANUPL
14000 WMOT=(.9000001*GRADE/MOTSW)*WT
14010 IF CAP%=4 OR CAP%=5 THEN WCON=(GRADE/CONSW)*WT
14020 IF CAP%=5 THEN WTF=(GRADE/TRFSW)*WT
14030 IF CAP%=2 OR CAP%=6 THEN WCON=(CYCLE/CONSW)*WT
14040 IF CAP%=2 OR CAP%=6 THEN WTF=(CYCLE/TRFSW)*WT
14050 IF CAP%=4 THEN WTF=(GRADE/TRFSW)*WT
14060 IF CAP%=4 AND VEH%=2 THEN WTCVT=(GRADE/TRCVTSW)*WT
14070 IF CAP%=5 AND VEH%=2 THEN WTCVT=(GRADE/TRCVTSW)*WT
14071 IF CAP%=2 OR CAP%=6 THEN ETKW=CYCLE*WT/1000
14072 IF CAP%=4 THEN ETKW=GRADE*WT/1000
14073 IF CAP%=5 THEN ETKW=GRADE*WT/1000
14074 IF VEH%=2 AND CAP%=4 THEN EPOW=GRADE*WT/1000
14075 IF VEH%=2 AND CAP%=5 THEN EPOW=GRADE*WT/1000
14076 IF VEH%=2 THEN ENGKW=EPOW
14077 IF VEH%=2 THEN ENGHP=EPOW/.7460001
14078 IF CAP%=2 OR CAP%=6 THEN CKW=CYCLE*WT/1000
14079 IF CAP%=4 OR CAP%=5 THEN CKW=GRADE*WT/1000
14080 IF VEH%=1 THEN WTCVT1=0 ELSE WTCVT=(GRADE/TRCVTSW)*WT
14081 PEFPWR=.9*GRADE*WT/1000
14090 IF VEH%=2 THEN WHE=(GRADE/HESW)*WT ELSE WHE=0
```

```
14092 VCT=CKW/2.15
14093 VTT1F=ETKW/2.8
14094 IF VEH%=1 THEN GOTO 14097
14095 ENGVOL=EPOW/.5
14096 OTRANVOL=EPOW/.0499999
14097 REM DATA ON WH/L ARE FROM SYMONS EQUATIONS
14098 REM AL-AIR WH/L WAS TAKEN FROM GREY REPORT
14100 REM NI-ZN WH/L WAS TAKEN FROM GREY REPORT
14101 BVOL=(Q1*WB)/Q2
14102 PB=(PBC*WB)/1000
14109 RETURN
14110 '*********************************************************************
14120 '
14130 REM SUBROUTINE HYBRID
14140 '
14150 '*********************************************************************
14151 PRINT#1, "USERDATA"
14152 PRINT#1, "ADVICE"
14153 PRINT#1, "NAMCLC CVRT"
14154 PRINT#1, "NAMHE AUDI1700"
14155 PRINT#1, "FUELCP 10GAL"
14157 PRINT#1, "EFFBC 0.9"
14158 PRINT#1, "FBRKS 0.3"
14159 PRINT#1, "EFCVRT 0.9"
14160 PRINT#1, "WT";WT
14162 PRINT#1, "WB";WB
14164 PRINT#1, "CDA";CDA
14166 PRINT#1, "CRDIAL";CRDIAL
14168 PRINT#1, "PTIRE";PTIRE
14170 PRINT#1, "CHGENG"
14180 PRINT#1, "N"
14190 PRINT#1, "9"
14200 PRINT#1, "3"
14210 PRINT#1, "11"
14220 PRINT#1, ENGHP
14230 PRINT#1, "NONE"
14240 RETURN
14250 '*********************************************************************
14260 '
14270 REM SUBROUTINE DATA
14280 '
14290 '*********************************************************************
14292 PRINT#1, "SLFDSC";SLFD
14295 PRINT#1, "ECHO ON"
14298 PRINT#1, "PACC";PACC
14300 PRINT#1, "WT";WT
14310 PRINT#1, "WB";WB
14320 PRINT#1, "CDA";CDA
14330 PRINT#1, "CRDIAL";CRDIAL
14340 PRINT#1, "PTIRE";PTIRE
14350 PRINT#1, "PEFPWR KW";PEFPWR;PEFPWR
14360 PRINT#1, "PMXANL"+STR$(PMXANL)+"KW"
14370 PRINT#1, "PKEFF";PKEFF;PKEFF
14380 PRINT#1, "EFFCD";EFFCD
14390 IF NUM%<>4 THEN PRINT#1, "CH";CH(1);CH(2);CH(3)
14400 RETURN
```

BLOCK DIAGRAM



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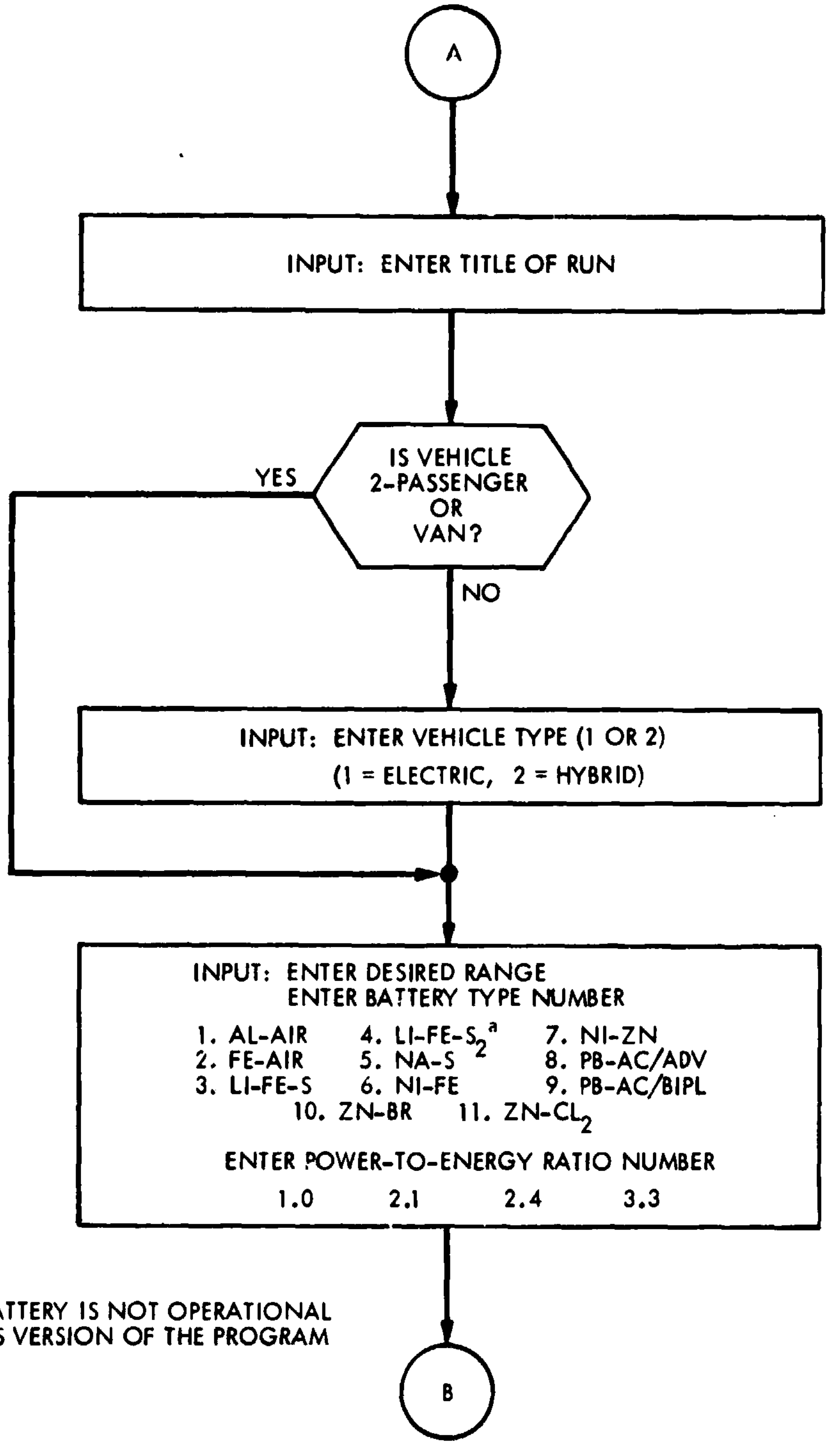
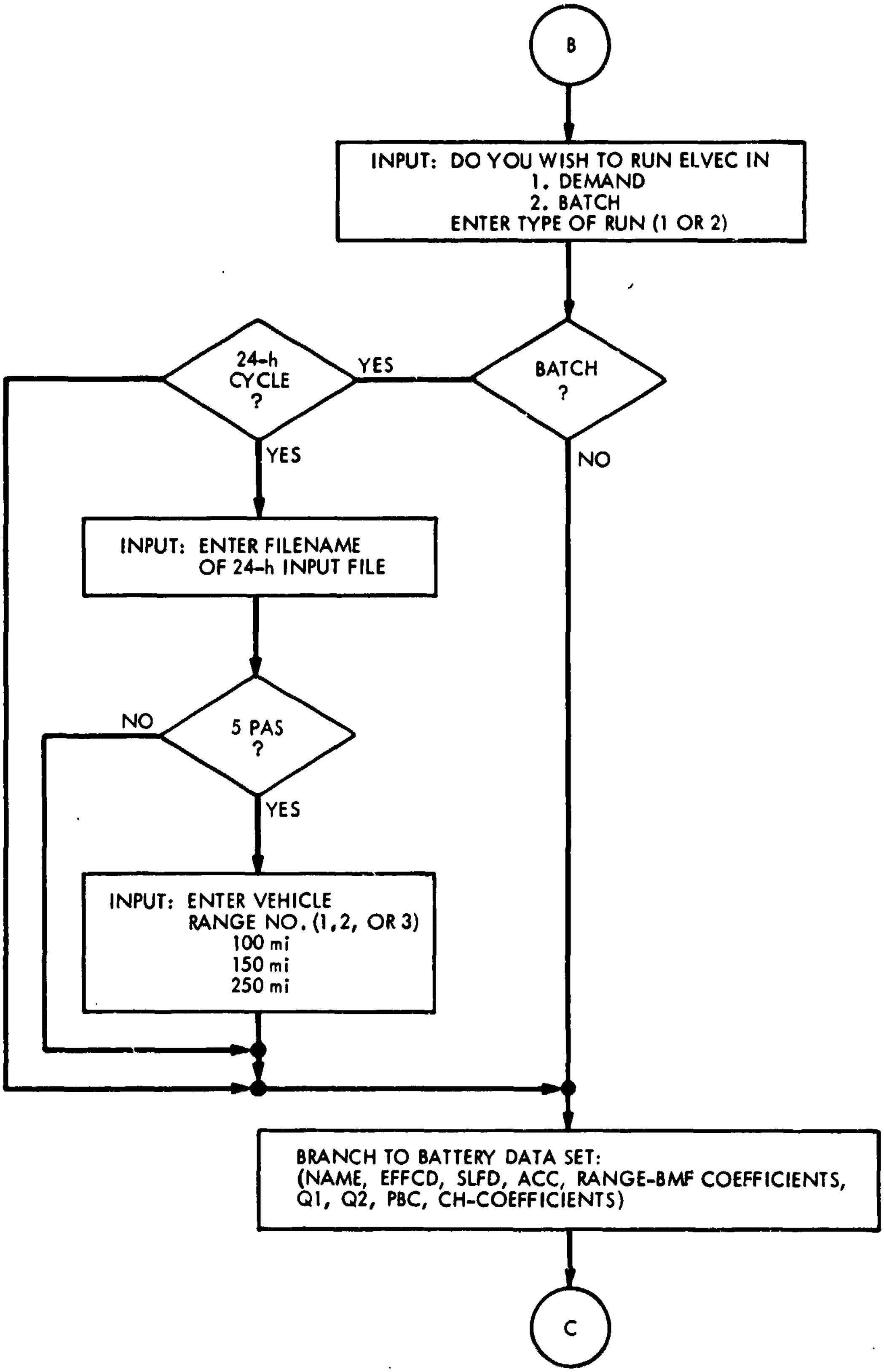
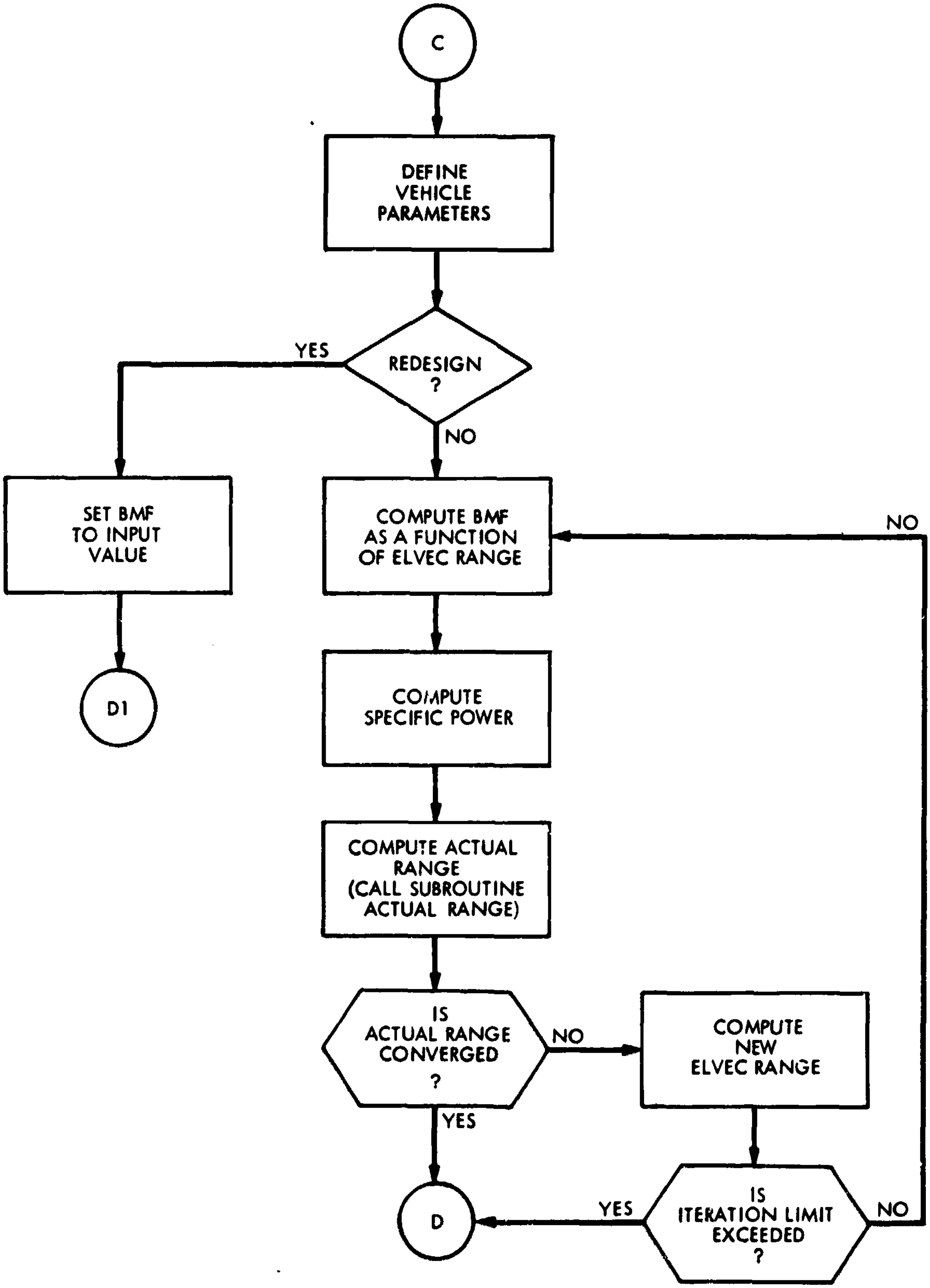
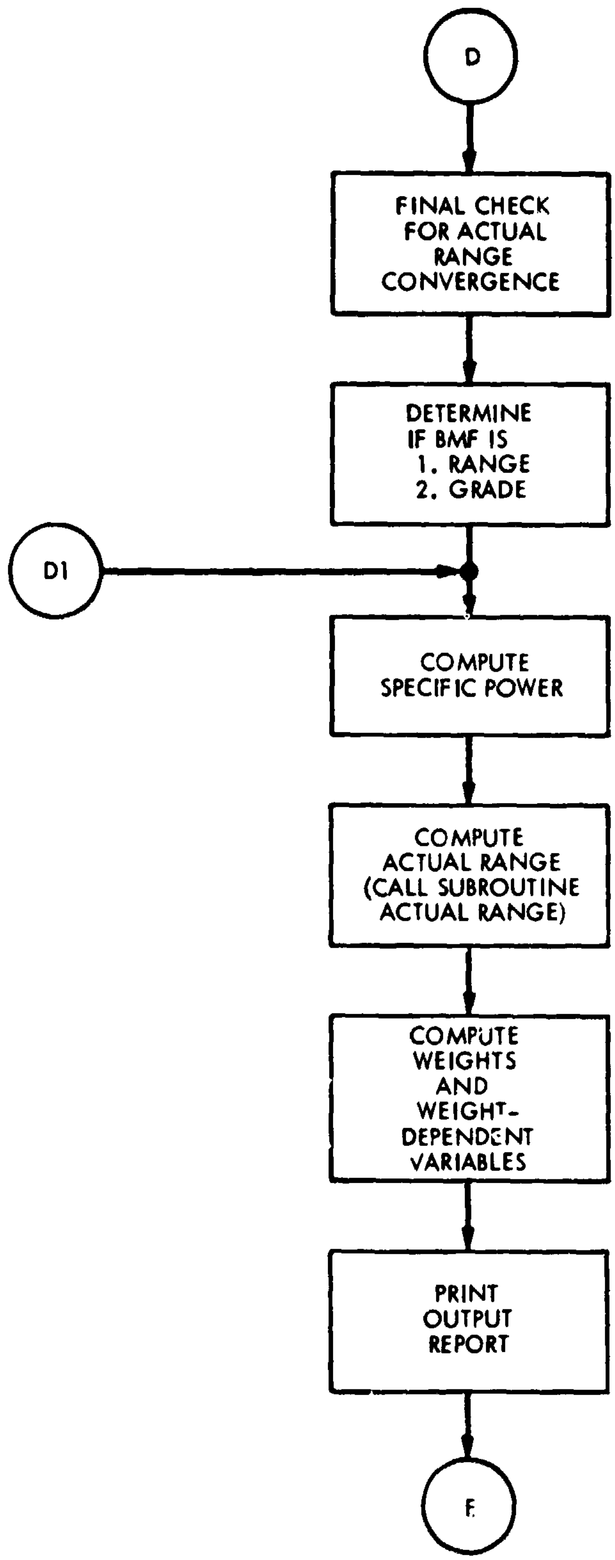
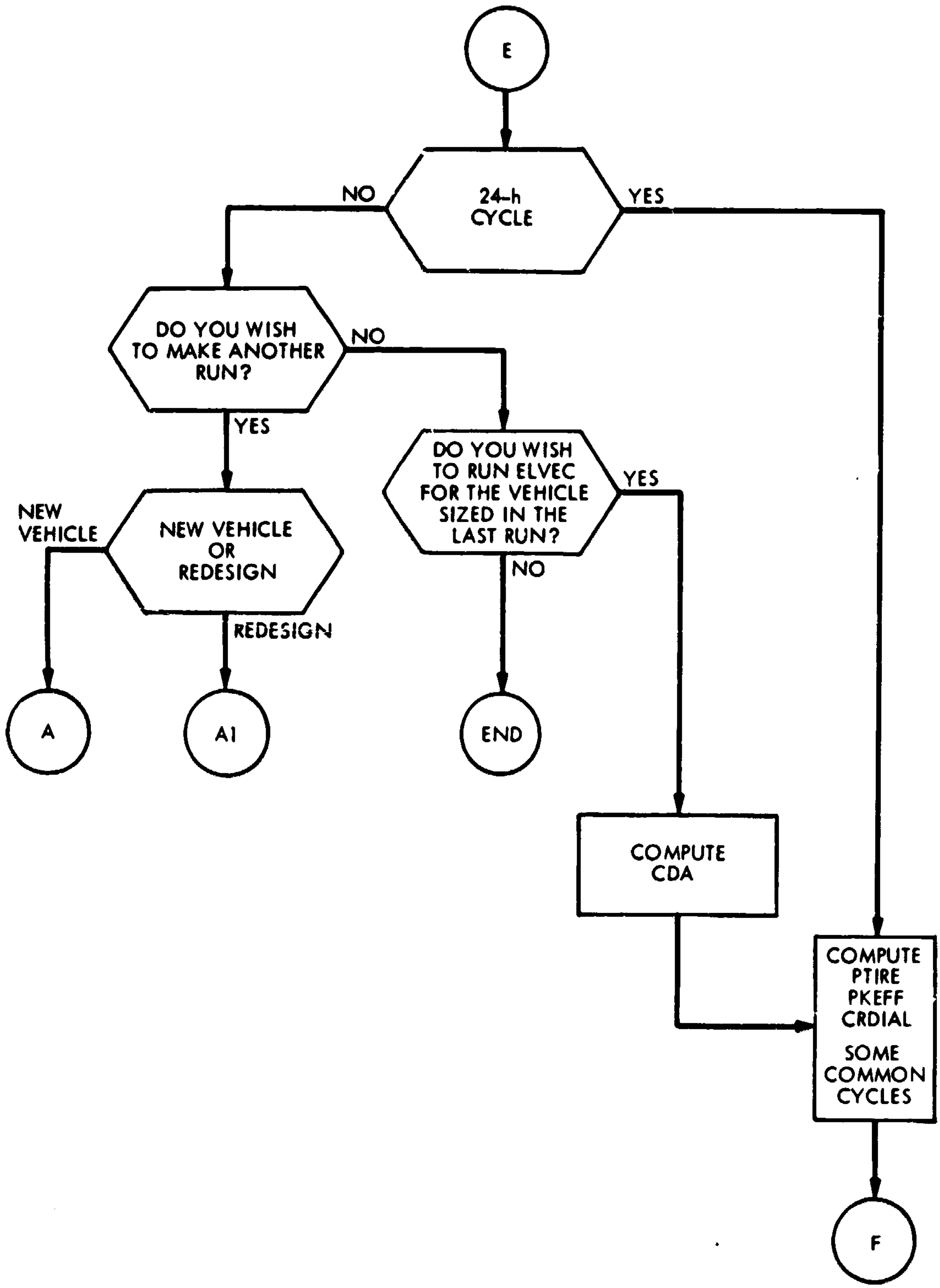


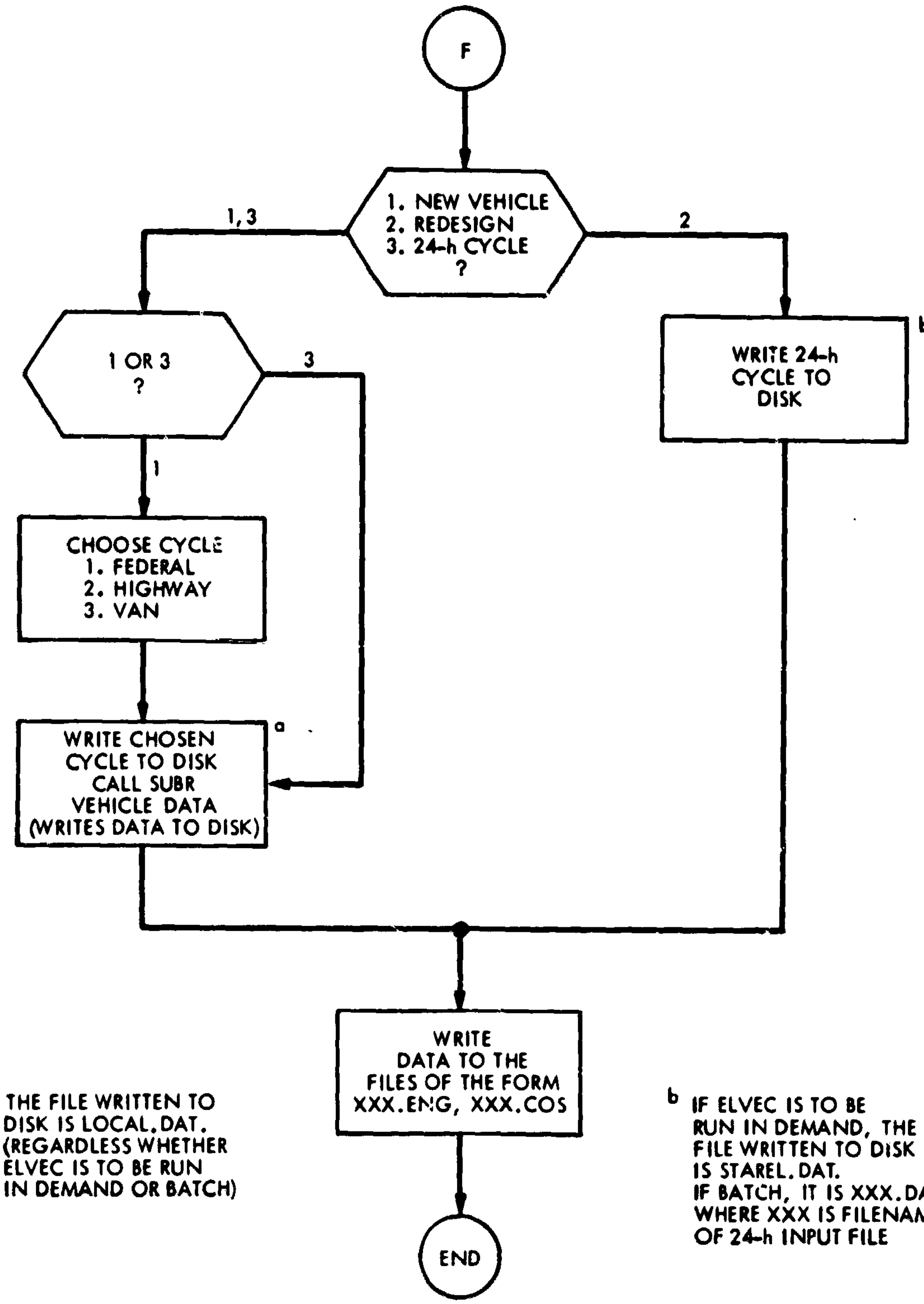
[a] THIS BATTERY IS NOT OPERATIONAL IN THIS VERSION OF THE PROGRAM


B
INPUT: DO YOU WISH TO RUN ELVEC IN
1. DEMAND
2. BATCH
ENTER TYPE OF RUN (1 OR 2)
BATCH ?
NO
YES
24-h CYCLE ?
YES
INPUT: ENTER FILENAME OF 24-h INPUT FILE
5 PAS ?
NO
YES
INPUT: ENTER VEHICLE RANGE NO. (1,2, OR 3)
100 mi
150 mi
250 mi
BRANCH TO BATTERY DATA SET:
(NAME, EFFCD, SLFD, ACC, RANGE-BMF COEFFICIENTS,
Q1, Q2, PBC, CH-COEFFICIENTS)
C


C
DEFINE VEHICLE PARAMETERS
REDESIGN ?
YES
NO
SET BMF TO INPUT VALUE
D1
COMPUTE BMF AS A FUNCTION OF ELVEC RANGE
NO
COMPUTE SPECIFIC POWER
COMPUTE ACTUAL RANGE (CALL SUBROUTINE ACTUAL RANGE)
IS ACTUAL RANGE CONVERGED ?
NO
COMPUTE NEW ELVEC RANGE
YES
D
YES
IS ITERATION LIMIT EXCEEDED ?
NO


D
FINAL CHECK FOR ACTUAL RANGE CONVERGENCE
DETERMINE IF BMF IS 1. RANGE 2. GRADE
D1
COMPUTE SPECIFIC POWER
COMPUTE ACTUAL RANGE (CALL SUBROUTINE ACTUAL RANGE)
COMPUTE WEIGHTS AND WEIGHT-DEPENDENT VARIABLES
PRINT OUTPUT REPORT
F


E
24-h CYCLE
NO
YES
DO YOU WISH TO MAKE ANOTHER RUN?
NO
YES
DO YOU WISH TO RUN ELVEC FOR THE VEHICLE SIZED IN THE LAST RUN?
YES
NO
NEW VEHICLE
NEW VEHICLE OR REDESIGN
REDESIGN
A
A1
END
COMPUTE CDA
COMPUTE PTIRE PKEFF CRDIAL
SOME COMMON CYCLES
F



[a] THE FILE WRITTEN TO DISK IS LOCAL.DAT. (REGARDLESS WHETHER ELVEC IS TO BE RUN IN DEMAND OR BATCH)

[b] IF ELVEC IS TO BE RUN IN DEMAND, THE FILE WRITTEN TO DISK IS STAREL.DAT. IF BATCH, IT IS XXX.DAT WHERE XXX IS FILENAME OF 24-h INPUT FILE

COMMAND FILES

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```
$ TYPE MAX.COM

$ set noverify
$ ON CONTROL_Y THEN $GOTO EXIT
$ inq rsp "Do you want to see 1 July message? "
$ if rsp.eqs."Y" then TYPE SIAO:[GRCUSER.STORE]MSG284.LIS
$ inq rsp "BULK DATA FILE TO BE USED(NULL RETURN FOR DEFAULT)? "
$ if rsp.eqs."" then goto default
$ assign/user 'rsp'                          for009
$ goto continue
$ default:
$ assign/USER SIAO:[GRCUSER]bulk.dat         for009
$ continue:
$ assign/USER sav.dat                        for012
$ assign/USER STAREL.COM                     for005
$ assign/USER sys$output                     for006
$ ON ERROR THEN $ GOTO EXIT
$ run SIAO:[GRCUSER]ELV.EXE
$ EXIT:
$ del sav.dat;*


$ TYPE RUNELVEC.COM

$ set noverify
$ ON CONTROL_Y THEN $GOTO EXIT
$ inq rsp "Do you want to see 1 Jul message? "
$ if rsp.eqs."Y" then TYPE SIAO:[GRCUSER.STORE]MSG284.LIS
$ inq rsp "BULK DATA FILE TO BE USED(NULL RETURN FOR DEFAULT)? "
$ if rsp.eqs."" then goto default
$ assign/user 'rsp'                          for009
$ goto continue
$ default:
$ assign/USER SIAO:[GRCUSER]bulk.dat         for009
$ continue:
$ assign/USER sav.dat                        for012
$ assign/USER sys$command                    for005
$ assign/USER sys$output                     for006
$ ON ERROR THEN $ GOTO EXIT
$ run SIAO:[GRCUSER]elv.exe
$ EXIT:
$ del sav.dat;*
```

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GLOSSARY

GLOSSARY

NAME	DEFINITION
A	coefficient of the battery mass fraction (BMF) - ELVEC range (R) equation. viz., BMF= AR+ B
ACC	Defined by PACC = ACC*WB
ACCN	Acceleration power (kw)
ACTRAN	Actual range (miles)
ANS$	String variable which obtains the response to question "DO YOU WISH TO MAKE ANOTHER RUN? If not Y or N (including lower case forms) then try again.
ANS1$	String variable which obtains the response to the question "DO YOU WISH TO RUN ELVEC FOR THE VEHICLE SIZED IN THE LAST RUN?" If not Y or N (including lower case forms) then try again.
B	Coefficient of the battery mass fraction (BMF)-ELVEC range (R) equation viz., BMF = AR + B
BATN$ (I)	Battery name
BMF	Battery mass fraction
BMFIN	Battery mass fraction input by the user in the redesign mode.
BMF1	BMF1 = GRADE/PD
BMF2	BMF value in the file VEHICLE.DAT
BVOL	Battery volume (1)

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CAP%	Vehicle capacity
CDA	Drag coefficient
CH(I)	CH-coefficients
CKW	controller power (kw)
CNUM%	Cycle type number: 1 = Federal cycle 2 = Highway cycle 3 = Van cycle
CONSW	Controller specific weight
CRDIAL	ELVEC variable
CYCLE	Cycle power
CYCLE%	Sets number of cycles in 24-hour cycle
CY$(I)	String variable used to label cycle number in the TITLE field of the ELVEC program
DOB%	Flag which determines whether 24-hr. cycle will be run in demand or batch. (If set to 1 then demand; if set to 2 then batch).
DOD	Cut off depth of discharge
DOM(I)	Specific power values for the tables in the subroutine which computes actual range.
DRAN	Desired range (miles)

EFCVRT	efficiency of CVT
EFFBC	battery charger efficiency
EFFCD	charge-discharge efficiency
ENGHP	defined by: ENGHP=ENGKW/0.746
ENGKW	for hybrids defined by ENGKW = EPOW
ENGVOL	engine volume (1)
EPOW	defined by: EPOW=GRADE*WT/1000
ERROR%	Flag set equal to 1 if the specific power is out of range
ETKW	equal to GRADE*WT/1000 or CYCLE*WT/1000
FBRKS	fraction of braking energy dissipated by friction
FUELCP	fuel capacity
GRADE	grade power (kw)
GTRANVOL	ICE transmission volume (1)
HESW	Heat engine specific power (w/kg)
LIMPRT%	Flag set equal to 1 if the iteration limit is exceeded in the iteration procedure for actual range.
MOTSW	Motor specific power (w/kg)
MT	Motor type (not operational in this version of the program)

N	the number of points used to define the SPECIFIC POWER X DOD functions. The value of N is dependent upon battery type. However, it is fixed for each run.
NAM$	String variable which obtains the current battery name.
NUM%	Battery type number. An integer input variable which directs the program's branching to the correct data set for the desired battery. Must obtain a value between 1 and 11 (inclusive) or try again.
PACC	Accessory power (kw)
PANDPL	Passenger and payload wt (kg)
PB	Battery power (kw)
PBC	constant in battery power equation
PD	power density
PE$(I)	power/energy ratio
PTIRE	pressure of tires (lbs/sq.in.)
PTOR%	value of the variable TOR% for "previous" run.
Q1	Constant in battery volume equation
Q2	Constant in battery volume equation
RAN(I)	Cut off DOD values for the tables in the subroutine which computes actual range.

RF%	Internal integer variable such that if it is equal to zero then the header of the output report is printed. if it is equal to one then the header is not printed.
SLFD	self discharge (kw-hr)
SNUM%	Integer variable which sets the power to energy ratio according to: 1 means P/E = 1.0 2 means P/E = 2.1 3 means P/E = 2.4 4 means P/E = 3.3
TLE$	Title of run
TOR%	Integer variable with the following settings: 1 means new vehicle 2 means 24-hr. cycle using previous vehicle 3 means redesign by entering BMF.
TRCVTSW	CVT specific weight
TRFSW	fixed transmission specific weight
VCT	controller volume (1)
VEH%	vehicle type number 1 = electic 2 = hybrid
VMOT	motor volume (1)
VTT1F	EV transmission volume (1)
WCON	controller weight (kg)
WCON1	term in basic weight equation

WHE	weight of the heat engine (kg)
WHE1	term in basic weight equation
WKG	specific power (w/kg)
WMOT	Motor weight (kg)
WSH	shell weight (kg)
WTCVT	CVT weight (kg)
WTCVT1	term in basic weight equation
WTF	Fixed transmission weight (kg)
WTF1	term in basic weight equation
WTR1	term in basic weight equation

LISTINGS FOR AVENERGY AND AVCOST

```
0     ' AVENERUY.001 - COMBINED PROGRAM FOR 2, 4, 5 PASSENGER AND VAN
10 ' SUBROUTINE LISTING
380 INPUT "ENTER FILE NAME OF THE FORM XXX.ENG : " , ENG$
385 '
390 GOSUB 25000 ' INITIALIZATION ROUTINE
395 '
400 OPEN ENG$ FOR INPUT AS #3
410 INPUT#3, WB,WT,TIT$,VEH
420 CLOSE#3
430 '
440 REM REQUEST ELVEC OUTPUT FILE
450 '
460 INPUT "ENTER ELVEC OUTPUT FILE NAME (NULL IF NO FILE IS BEING USED) : " ,JRB$
470 IF JRB$="" THEN ELFLAG=0 ELSE ELFLAG=1
475 IF ELFLAG=1 THEN OPEN JRB$ FOR INPUT AS #2
477 IF ELFLAG=1 THEN INPUT#2, DUMMY1,DUMMY2,RANGE(1),ACTRNG(1),DODMX,PDMAX(1),
    WHPM(1),GPM(1),DAT$(1),TIM$(1)
480 CLOSE #2
510 PRINT "SELECT THE VEHICLE AS FOLLOWS:"
520 PRINT "      1 - TWO-PASSENGER - 9 CYCLES"
530 PRINT "      2 - FOUR-PASSENGER 250m - 12 CYCLES"
540 PRINT "      3 - FIVE-PASSENGER 100m - 10 CYCLES"
550 PRINT "      4 - FIVE-PASSENGER 150m - 11 CYCLES"
560 PRINT "      5 - FIVE-PASSENGER 250m - 12 CYCLES"
570 PRINT "      6 - VAN - 4 CYCLES"
580 PRINT "      0 - EXIT PROGRAM - RETURN TO BASIC"
590 INPUT "PICK A NUMBER ",NPAS
600 IF NPAS=0 THEN CLOSE:END
610 IF NPAS>6 OR NPAS<1 THEN CLS:GOTO 510
620 GOSUB 23000 ' VEHICLE TYPE AND INFO SUBROUTINE
625 RESTORE
630 ON NPAS GOSUB 1000,2000,3000,4000,5000,6000
640 CLS:GOTO 510
1000 'S 1000 SUBROUTINE - 2 PASSENGER - 9 CYCLE
1010 Z=9
1020 GOSUB 10000 ' READ CAR DATA
1030 IF ELFLAG=0 THEN GOSUB 13000 ELSE GOSUB 27000
1040 IF VEH=1 THEN GOSUB 1100
1050 IF VEH=2 THEN GOSUB 1500
1060 RETURN
1100 '2 PASSENGER - 9 CYCLE - VEH = 1
1110 GOSUB 14000 ' PRINT 1 SUBROUTINE
1120 GOSUB 16000 ' PRINT 3 SUBROUTINE
1130 'GOSUB 17000 ' PRINT 4 SUBROUTINE
1150 GOSUB 18000 ' PRINT 5 SUBROUTINE
1160 GOSUB 24000 ' CLOSING SUBROUTINE
1170 RETURN
1500 ' 2 PASSENGER - 9CYCLE - VEH = 2
1510 GOSUB 15000 ' PRINT 2 SUBROUTINE
1520 GOSUB 16000 ' PRINT 3 SUBROUTINE
1530 GOSUB 17000 ' PRINT 4 SUBROUTINE
1550 GOSUB 18000 ' PRINT 5 SUBROUTINE
1560 GOSUB 20000 ' PRINT 6 SUBROUTINE
1570 GOSUB 24000 ' CLOSING SUBROUTINE
1580 RETURN
2000 'S 2000 SUBROUTINE - 4 PASSENGER - 12 CYCLE - 250m
2010 Z=12
2020 GOSUB 10000 ' READ CAR DATA
2030 IF ELFLAG=0 THEN GOSUB 13000 ELSE GOSUB 27000
2040 IF VEH=1 THEN GOSUB 2100
2050 IF VEH=2 THEN GOSUB 2500
2060 RETURN
2100 '4 PASSENGER - 12 CYCLE - 250m - VEH = 1
```

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```
2110 GOSUB 14000 ' PRINT 1 SUBROUTINE
2120 GOSUB 16000 ' PRINT 3 SUBROUTINE
2130 'GOSUB 17000 ' PRINT 4 SUBROUTINE
2150 GOSUB 18000 ' PRINT 5 SUBROUTINE
2160 GOSUB 24000 ' CLOSING SUBROUTINE
2170 RETURN
2500 '4 PASSENGER - 12 CYCLE - 250m - VEH = 2
2510 GOSUB 15000 ' PRINT 2 SUBROUTINE
2520 GOSUB 16000 ' PRINT 3 SUBROUTINE
2530 GOSUB 17000 ' PRINT 4 SUBROUTINE
2550 GOSUB 18000 ' PRINT 5 SUBROUTINE
2560 GOSUB 20000 ' PRINT 6 SUBROUTINE
2570 GOSUB 24000 ' CLOSING SUBROUTINE
2580 RETURN
3000 'S 3000 SUBROUTINE - 5 PASSENGER - 10 CYCLE - 100m
3010 Z=10
3020 GOSUB 10000 ' READ CAR DATA
3030 IF ELFLAG=0 THEN GOSUB 13000 ELSE GOSUB 27000
3040 IF VEH=1 THEN GOSUB 3100
3050 IF VEH=2 THEN GOSUB 3500
3060 RETURN
3100 '5 PASSENGER - 10 CYCLE - 100m - VEH = 1
3110 GOSUB 14000 ' PRINT 1 SUBROUTINE
3120 GOSUB 16000 ' PRINT 3 SUBROUTINE
3130 'GOSUB 17000 ' PRINT 4 SUBROUTINE
3150 GOSUB 18000 ' PRINT 5 SUBROUTINE
3160 GOSUB 24000 ' CLOSING SUBROUTINE
3170 RETURN
3500 '5 PASSENGER - 10 CYCLE - 100m - VEH = 2
3510 GOSUB 15000 ' PRINT 2 SUBROUTINE
3520 GOSUB 16000 ' PRINT 3 SUBROUTINE
3530 GOSUB 17000 ' PRINT 4 SUBROUTINE
3550 GOSUB 18000 ' PRINT 5 SUBROUTINE
3560 GOSUB 20000 ' PRINT 6 SUBROUTINE
3570 GOSUB 24000 ' CLOSING SUBROUTINE
3580 RETURN
4000 'S 4000 SUBROUTINE - 5 PASSENGER - 11 CYCLE - 150m
4010 Z=11
4020 GOSUB 10000 ' READ CAR DATA
4030 IF ELFLAG=0 THEN GOSUB 13000 ELSE GOSUB 27000
4040 IF VEH=1 THEN GOSUB 4100
4050 IF VEH=2 THEN GOSUB 4500
4060 RETURN
4100 '5 PASSENGER - 11 CYCLE - 150m - VEH = 1
4110 GOSUB 14000 ' PRINT 1 SUBROUTINE
4120 GOSUB 16000 ' PRINT 3 SUBROUTINE
4130 'GOSUB 17000 ' PRINT 4 SUBROUTINE
4150 GOSUB 18000 ' PRINT 5 SUBROUTINE
4160 GOSUB 24000 ' CLOSING SUBROUTINE
4170 RETURN
4500 '5 PASSENGER - 11 CYCLE - 150m - VEH = 2
4510 GOSUB 15000 ' PRINT 2 SUBROUTINE
4520 GOSUB 16000 ' PRINT 3 SUBROUTINE
4530 GOSUB 17000 ' PRINT 4 SUBROUTINE
4550 GOSUB 18000 ' PRINT 5 SUBROUTINE
4560 GOSUB 20000 ' PRINT 6 SUBROUTINE
4570 GOSUB 24000 ' CLOSING SUBROUTINE
4580 RETURN
5000 'S 5000 SUBROUTINE - 5 PASSENGER - 12 CYCLE - 250m
5010 Z=12
5020 GOSUB 10000 ' READ CAR DATA
5030 IF ELFLAG=0 THEN GOSUB 13000 ELSE GOSUB 27000
5040 IF VEH=1 THEN GOSUB 5100
```

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OF POOR QUALITY

```
5050 IF VEH=2 THEN GOSUB 5500
5060 RETURN
5100 'S PASSENGER - 12 CYCLE - 250m - VEH = 1
5110 GOSUB 14000 ' PRINT 1 SUBROUTINE
5120 GOSUB 16000 ' PRINT 3 SUBROUTINE
5130 'GOSUB 17000 ' PRINT 4 SUBROUTINE
5150 GOSUB 18000 ' PRINT 5 SUBROUTINE
5160 GOSUB 24000 ' CLOSING SUBROUTINE
5170 RETURN
5500 'S PASSENGER - 12 CYCLE - 250m - VEH = 2
5510 GOSUB 15000 ' PRINT 2 SUBROUTINE
5520 GOSUB 16000 ' PRINT 3 SUBROUTINE
5530 GOSUB 17000 ' PRINT 4 SUBROUTINE
5550 GOSUB 18000 ' PRINT 5 SUBROUTINE
5560 GOSUB 20000 ' PRINT 6 SUBROUTINE
5570 GOSUB 24000 ' CLOSING SUBROUTINE
5580 RETURN
6000 'S 6000 SUBROUTINE - VAN - 4 CYCLE
6010 Z=4
6020 GOSUB 11000 ' READ VAN DATA
6030 IF ELFLAG=0 THEN GOSUB 13000 ELSE GOSUB 27000
6040 IF VEH=1 THEN GOSUB 6100
6050 IF VEH=2 THEN GOSUB 6500
6060 RETURN
6100 'VAN - 4 CYCLE - VEH = 1
6110 GOSUB 14000 ' PRINT 1 SUBROUTINE
6120 GOSUB 16000 ' PRINT 3 SUBROUTINE
6130 'GOSUB 17000 ' PRINT 4 SUBROUTINE
6150 GOSUB 18000 ' PRINT 5 SUBROUTINE
6160 GOSUB 24000 ' CLOSING SUBROUTINE
6170 RETURN
6500 'VAN - 4 CYCLE - VEH = 2
6510 GOSUB 15000 ' PRINT 2 SUBROUTIN
6520 GOSUB 16000 ' PRINT 3 SUBROUT
6530 GOSUB 17000 ' PRINT 4 SUBROUTI
6550 GOSUB 18000 ' PRINT 5 SUBROUTIN
6560 GOSUB 20000 ' PRINT 6 SUBROUTINE
6570 GOSUB 24000 ' CLOSING SUBROUTINE
6580 RETURN
10000 'CAR DATA READ SUBROUTINE
10010 FOR I=1 TO Z
10020 READ M(I),DAYS(I):NEXT I
10030 DATA 4,2,57
10040 DATA 7,45,50
10050 DATA 8,2,43
10060 DATA 16,86,32
10070 DATA 22,35,63
10080 DATA 27,27
10090 DATA 45,4,29
10100 DATA 59,6,18
10110 DATA 73,6,19
10120 DATA 105,5,8
10130 DATA 158,4,7
10140 DATA 250,4
10150 RETURN
11000 'VAN DATA READ SUBROUTINE
11001 M(1)=25:DAYS(1)=163
11002 M(2)=35:DAYS(2)=62
11003 M(3)=45:DAYS(3)=25
11004 M(4)=55:DAYS(4)=12
11010 'FOR I=1 TO Z
11020 'READ M(I),DAYS(I):NEXT I
11030 'DATA 25,163
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11040 'DATA 35,62
11050 'DATA 45,25
11060 'DATA 55,12
11070 RETURN
13000 'VEHICLE CONSUMPTION AND RANGE SUBROUTINE
13010 PRINT "INPUT THE RANGE,ENERGY CONSUMPTION AND MPG FOR EACH CYCLE"
13020 LPRINT "CYCLE", "RANGE"," WH/MILE","MPG"
13030 FOR I=1 TO Z
13040 PRINT "CYCLE ";I;:INPUT RANGE(I),WHPM(I),MPG(I)
13050 LPRINT          I,       RANGE(I),WHPM(I),MPG(I)
13060 NEXT I
13070 RETURN
14000 'PRINT 1 SUBROUTINE
14010 FOR I=1 TO Z
14020 MILES(I)=M(I)*DAYS(I)
14030 EL(I)=WHPM(I)*MILES(I)/1000
14040 IF M(I)>RANGE(I) THEN MILES(I)=RANGE(I)*DODMX*DAYS(I)
14050 DOD(I)=M(I)/RANGE(I)
14060 IF M(I)>RANGE(I) THEN DOD(I)=DODMX
14070 D=D+MILES(I):E=E+EL(I)
14080 CYCLES(I)=DOD(I)*DAYS(I)
14090 X=X+CYCLES(I)
14100 NEXT I
14110 LPRINT "cycle","wh/mile","miles/day","days","cum miles","kwh","DOD","cycles"
14120 FOR I=1 TO Z
14130 PRINT I,WHPM(I),M(I),DAYS(I),MILES(I),EL(I),DOD(I),CYCLES(I)
14140 LPRINT I,WHPM(I),M(I),DAYS(I),MILES(I),EL(I),DOD(I),CYCLES(I)
14150 NEXT I
14160 RETURN
15000 'PRINT 2 SUBROUTINE
15010 FOR I=1 TO Z
15020 K=RANGE(I)*DODMX:MILES(I)=DAYS(I)*M(I)
15030 IF M(I)>K THEN GOSUB 15500 ELSE GOSUB 15100
15035 NEXT I
15037 GOSUB 15800 ' PRINT 2-3 SUBROUTINE
15040 RETURN
15100 'PRINT 2-1 SUBROUTINE
15110 GM(I)=0:EM(I)=M(I):EL(I)=WHPM(I)*M(I)*DAYS(I)/1000
15120 DOD(I)=M(I)/RANGE(I)
15130 CYCLES(I)=DOD(I)*DAYS(I)
15140 RETURN
15500 'PRINT 2-2 SUBROUTINE
15510 GM(I)=M(I)-K:EL(I)=K*WHPM(I)*DAYS(I)/1000
15610 EM(I)=K:DOD(I)=DODMX
15720 RETURN
15800 'PRINT 2-3 SUBROUTINE
15805 LPRINT "cycle","wh/mi","e mi","f mi","mi/day","days","cum mi","kwh","dod","cycles"
15808 FOR I=1 TO Z
15810 CYCLES(I)=DOD(I)*DAYS(I)
15812 GM(9)=21.4
15814 GM(10)=44.8
15816 GM(11)=106.2
15818 GM(12)=197.8
15819 IF I<9 THEN GM(I)=0
15820 D=D+MILES(I):E=E+EL(I):X=X+CYCLES(I):G=G+GM(I)*DAYS(I):P=P+EM(I)*DAYS(I)
15860 LPRINT I,WHPM(I),EM(I),GM(I),M(I),DAYS(I),MILES(I),EL(I),DOD(I),CYCLES(I)
15870 PRINT I,WHPM(I),EM(I),GM(I),M(I),DAYS(I),MILES(I),EL(I),DOD(I),CYCLES(I)
15880 NEXT I
15890 RETURN
16000 'PRINT 3 SUBROUTINE
16010 LPRINT "-------------------------------------------------------------
16020 PRINT D;"miles",E;"kw-hrs",X,"cycles",G,"FUEL MILES",P,"miles on electric"
16030 LPRINT D;"miles",E;"kw-hrs",X,"cycles",G,"FUEL MILES",P,"miles on electric"
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16040 FUEL=G/D:ENER=P/D
16050 LPRINT "Electric...",ENER,"  Fuel...",FUEL
16060 PRINT "Electric...",ENER,"  Fuel...",FUEL
16070 LPRINT "Annual travel in km=";D*1.6
16080 DCON=D*1.6:ETKM=10*DCON:WC=WT-136:GAS=0
16090 'LPRINT "MPG-U=";MPGU;"MPG-H=";MPGH
16100 RETURN
17000 'PRINT 4 SUBROUTINE
17010 FOR I=1 TO Z
17012 GM(9)=21.4
17014 GM(10)=44.8
17016 GM(11)=106.2
17018 GM(12)=197.8
17019 IF I<9 THEN GM(I)=0
17020 IF I<9 THEN FC(I)=0
17025 'THE FOLLOWING ASSUMES METHANOL MPG INPUT - UNADJUSTED FROM ELVEC
17030 IF I>8 THEN FC(I)=DAYS(I)*GM(I)/(MPG(I)*1.1)
17040 GAS=GAS+(FC(I)/1.8)
17050 NEXT I
17060 LPRINT "Vehicle Curb weight in kg=";WC,"weight of the Battery=";WB
17070 RETURN
18000 'PRINT 5 SUBROUTINE
18020 LPRINT "Battery Cycle Life=";BCL;"Cycles"
18030 LPRINT "Depth of discharge,Average Daily=";X/365
18040 X365=X/365
18090 RETURN
20000 'PRINT 6 SUBROUTINE
20010 LPRINT "ANNUAL GASOLINE CONSUMPTION=";GAS;"GALLONS"
20020 GALM=GAS*1.8:LITM=GALM*3.8
20030 LPRINT"LITERS OF METHANOL=";LITM;"GALLONS OF METHANOL=";GALM
20040 RETURN
23000 'VEHICLE TYPE AND INFO SUBROUTINE
23010 REM * INPUT "PRINT THE TITLE";TIT$
23020 REM * INPUT "SELECT VEHICLE - 1 FOR EV , 2 FOR HV";VEH
23030 REM * INPUT "PRINT WT,WB";WT,WB
23050 INPUT "BATTERY CYCLE LIFE";BCL
23070 IF ELFLAG=0 THEN INPUT "MAX DOD";DODMX
23090 LPRINT TIT$
23100 RETURN
24000 'CLOSING SUBROUTINE
24030 OPEN "ENERGY.DAT" FOR OUTPUT AS #1
24040 WRITE #1, ETKM,E,ENER,FUEL,DCON,LITM,BCL,X365,WB,TIT$,VEH
24050 CLOSE #1
24060 LPRINT CHR$(12)
24070 RETURN
25000 'INITIALIZATION SUBROUTINE
25010 WIDTH "LPT1:",160
25020 LPRINT CHR$(27);"X";
25030 DIM AFM(12),EFM(12),FC(12),CYCLES(12),DOD(12),MPG(12),TRANGE(12)
25040 DIM M(12),DAYS(12),RANGE(12),WHPM(12),MILES(12),EL(12),GM(12),EM(12)
25045 DIM ACTRNG(12),PDMAX(12),GPM(12),DAT$(12),TIM$(12)
25050 D=0:E=0:X=0:G=0:P=0
25060 CLS : KEY OFF
25070 RETURN
27000 '
27010 'SUBROUTINE AUTOMATIC INPUT OF RANGE, ENERGY, DODMX AND MPG
27020 '
27022 PRINT : LPRINT
27023 LJRB=(132-LEN(JRB$))/2
27024 PRINT TAB(LJRB)JRB$
27025 LPRINT TAB(LJRB)JRB$
27026 PRINT : LPRINT
27030 OPEN JRB$ FOR INPUT AS #2
27040 INPUT#2, DUMMY1,DUMMY2,RANGE(1),ACTRNG(1),DODMX,PDMAX(1),WHPM(1),GPM(1),DAT$(1),TIM$(1)
27050 PRINT RANGE(1),ACTRNG(1),DODMX,PDMAX(1),WHPM(1),GPM(1),DAT$(1),TIM$(1)
27060 LPRINT RANGE(1),ACTRNG(1),DODMX,PDMAX(1),WHPM(1),GPM(1),DAT$(1),TIM$(1)
27065 IF VEH=2 AND GPM(1)<>0 THEN MPG(1)=1!/GPM(1)
27070 FOR I=2 TO Z
27080 INPUT#2, RANGE(I),ACTRNG(I), DODMX, PDMAX(I),WHPM(I),GPM(I),DAT$(I),TIM$(I)
27090 PRINT RANGE(I),ACTRNG(I),DODMX,PDMAX(I),WHPM(I),GPM(I),DAT$(I),TIM$(I)
27100 LPRINT RANGE(I),ACTRNG(I),DODMX,PDMAX(I),WHPM(I),GPM(I),DAT$(I),TIM$(I)
27105 IF VEH=2 AND GPM(I)<>0 THEN MPG(I)=1!/GPM(I)
27110 NEXT I
27120 PRINT : LPRINT
27130 CLOSE #2
27140 RETURN
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10 'AVCOST.BAS
20 KEY OFF:CLS
30 LPRINT CHR$(12)
40 LPRINT CHR$(27)+"5"
50 LPRINT CHR$(27) + "7"
60 OPEN "ENERGY.DAT" FOR INPUT AS #1
70 INPUT#1, TKM,AELC,EOLY,RICE,KMYR,AFUS,CYCB,ADOD,WB,PHD$,IVTYP
72 IF IVTYP=1 THEN VTYP=2 ELSE VTYPE=1
80 CLOSE #1
90 'TKM=128480!:AELC=3372:EOLY=1!:RICE=0:KMYR=12848:AFUS=0:CYCB=800
100 'ADOD=.329
105 INPUT "ENTER THE FILE NAME OF THE FORM XXX.CUS : " , CST$
110 OPEN CST$ FOR INPUT AS #3
120 INPUT#3, MKW,CKW,ETKW,EPOW,BATT$,CURBWT
130 CLOSE #3
140 'PEFPWR=30:CKW=35:ETKW:35:EPOW=40
150 'LINE INPUT "TYPE THE PAGE HEADING.  ":PHD$
160 REM ** INPUT "TYPE THE NAME OF THE BATTERY.  ":BATT$
170 IDOL=1982
180 IF IDOL=0 THEN IDOL=1982
190 REM # INPUT "Enter 1 for hybrid, 2 for electric ,3 for ice vehicle":VTYP
200 PRINT "Type the number of passengers as follows:"
210 PRINT "      1 - TWO-PASSENGER"
220 PRINT "      2 - FOUR-PASSENGER 250m"
230 PRINT "      3 - FIVE-PASSENGER 250m"
240 PRINT "      4 - FIVE-PASSENGER 100M"
250 PRINT "      5 - FIVE-PASSENGER 150M"
260 PRINT "      6-VAN "
270 INPUT "      ":NPAS
280 ON NPAS GOTO 290,300,310,320,330,340
290 PASS$="2-PASS" :PANDPL=136: GOTO 350
300 PASS$="4-PASS" :PANDPL=136: GOTO 350
310 PASS$="5-PASS" :PANDPL=136: GOTO 350
320 PASS$="5-PASS" :PANDPL=136: GOTO 350
330 PASS$="5-PASS" :PANDPL=136: GOTO 350
340 PASS$="VAN": PANDPL=295
350 REM
360 LACC=200
370 REM ** INPUT "Type the vehicle curb weight in KG.":CURBWT
380 IF NPAS=6 GOTO 410
390 WT=CURBWT+136
400 GOTO 415
410 WT=CURBWT+295
415 IF VTYP=3 THEN GOTO 482
420 'PRINT "Input section for battery data "
430 'REM * INPUT "Type battery weight in kg.":WB
455 INPUT "Type the cost of electricity in C/KW-H.":PELEC
457 PELEC=PELEC/100
460 INPUT "Type the battery shelf life in years.":BLIF
470 INPUT "Type the depth of a deep discharge (usually .8).":DDCG
480 IF DDCG=0 THEN DDCG=.8
482 INPUT "Type the vehicle maintenance factor--default=1":MFAC
484 IF MFAC=0 THEN MFAC=1
490 INPUT "enter the life of the vehicle in years":YEAR
495 IF VTYP=2 THEN RICE=0 :EOLY=1 :GOTO 560
497 IF VTYP=3 THEN RICE=1 :EOLY=0 :GOTO 700
570 PRINT
580 PRINT " Motor data"
582 INPUT "enter motor type:1 for ac,2 for dc brushless,3 for dc brush":MTYP
584 MTYP$="ac"
586 IF MTYP=2 THEN MTYP$="dc brushless"
588 IF MTYP=3 THEN MTYP$="dc brush"
590 PRINT
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600 REM ** INPUT "Type the power of the motor in KW.";MKW
620 'MKW=PEFPWR
630 MOTWT=MKW/.49
632 IF MTYP=2 THEN MOTWT=MKW/.64
634 IF MTYP=3 THEN MOTWT=MKW/.22
636 INPUT "enter controller type:1 for ac,2 for dc brushless,3 for dcbrush";CTYP

638 CTYP$="ac"
640 IF CTYP=2 THEN CTYP$="dc brushless"
641 IF CTYP=3 THEN CTYP$="dc brush"
645  REM ** INPUT "Type the controller rated power in kw.";CKW
650 CONWT=CKW/2.5
652 IF CTYP=2 THEN CONWT=CKW/.875
654 IF CTYP=3 THEN CONWT=CKW/1.47
660 REM ** INPUT "TYPE THE EV TRANSMISSION POWER IN KW";ETKW
670 MTYP$="AC" : IF MTYP=2 THEN MTYP$="DC"
680 PRINT
690 IF VTYP=2 THEN NTRAN=1 : GOTO 770
700 PRINT "Input section for engine"
710 PRINT
720 REM ** INPUT "Type the engine power in kw.";EPOW
730 ENGWT=EPOW/.45
740 REM ** INPUT "TYPE THE ICE TRANSMISSION POWER IN KW";TPOW : TPOW=EPOW
750 'INPUT "Type tank volume volume in L.   ";VGAS : VGAS=40
760 INPUT "1 TRANSMISSION OR 2";NTRAN
770 REM
775 TKM=YEAR*KMYR
800 INPUT "Type the vehicle salvage value as percent of new.";SLBV
810 SLBV=SLBV/100
812 'IF VTYP=3 THEN GOTO 814
814 'INPUT "ENTER THE ANNUAL TRAVEL IN KM/YR";KMYR
815 'IF VTYP=3 THEN GOTO 816
816 'INPUT "ENTER THE ANNUAL FUEL USE IN LITERS";AFUS
820 IF VTYP=2 THEN GOTO 870
830 INPUT "Type the cost of fuel for 1992 in 1982$/L";PFUEL
840 INPUT "Type 1 for gasoline fuel, 2 for diesel, 3 for methanol.";FTYP
850 FTYP$="GASOLINE" : IF FTYP=2 THEN FTYP$="DIESEL"
860 IF FTYP=3 THEN FTYP$="METHANOL"
870 INPUT "TYPE PERCENT REAL INTEREST RATE.";RINTR
880 INPUT "TYPE PERCENT REAL DISCOUNT RATE.";RDISR
890 INPUT "Type the number of years to finance over.";FYEAR
900 RINTR=RINTR/100
910 RDISR=RDISR/100
950 REM
960 REM
970 REM                 CALCULATIONS
980 IF VTYP=3 THEN GOTO 1270
990 IF NTRAN=2 THEN GOTO 1150
1000 PRINT "TYPE EV TRANSMISSION TYPE.  "
1010 PRINT "  1 - CVT"
1020 PRINT "  2 - 4-SPEED"
1030 PRINT "  3 - FIXED RATIO"
1035 INPUT "  4 - 2 speed auto";TTRAN
1040 ON TTRAN GOTO 1050,1060,1070,1080
1050 TRAN$="CVT" :TRANWT=ETKW/1.1: GOTO 1090
1060 TR( N$="4-speed" :TRANWT=ETKW/1.06: GOTO 1090
1070 TRAN$="fixed ratio" :TRANWT=ETKW/1.42: GOTO 1090
1080 TRAN$="2 speed auto" :TRANWT=ETKW/.86: GOTO 1090
1090 ON TTRAN GOTO 1100,1110,1120,1125
1100 COSTRAN=11.17*ETKW: GOTO 1400
1110 COSTRAN=5.58*ETKW: GOTO 1400
1120 COSTRAN=4.65*ETKW: GOTO 1400
1125 COSTRAN=5.4*ETKW: GOTO 1400
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1140 REM
1150 PRINT "TYPE EV TRANSMISSION TYPE.  "
1160 PRINT "  1 - CVT"
1170 PRINT "  2 - 4-speed"
1180 PRINT "  3 - fixed ratio"
1185 INPUT "  4 - 2 speed auto"!ETRAN
1190 ON ETRAN GOTO 1200,1210,1220,1225
1200 ETRAN$="CVT" !ETRANWT=ETKW/1.1! GOTO 1230
1210 ETRAN$="4-speed" !ETRANWT=ETKW/1.06! GOTO 1230
1220 ETRAN$="fixed ratio" !ETRANWT=ETKW/1.42! GOTO 1230
1225 ETRAN$="2 speed auto" !ETRANWT=ETKW/.86
1230 ON ETRAN GOTO 1240,1250,1260,1265
1240 ECOSTRAN=11.17*ETKW ! GOTO 1270
1250 ECOSTRAN=5.58*ETKW ! GOTO 1270
1260 ECOSTRAN=4.65*ETKW ! GOTO 1270
1265 ECOSTRAN=5.4*ETKW
1270 REM
1280 PRINT "TYPE ICE TRANSMISSION TYPE.   "
1290 PRINT "  1 - CVT"
1300 PRINT "  2 - 4-speed"
1310 PRINT "  3 - fixed ratio"
1315 INPUT " 2 speed auto"!GTRAN
1320 ON GTRAN GOTO 1330,1340,1350,1355
1330 GTRAN$="CVT" !GTRANWT=TPOW/1.1! GOTO 1360
1340 GTRAN$="4-speed" !GTRANWT=TPOW/1.06! GOTO 1360
1350 GTRAN$="fixed ratio" !GTRANWT=TPOW/1.42! GOTO 1360
1355 GTRAN$="2 speed auto" !GTRANWT=TPOW/.8599999
1360 ON GTRAN GOTO 1370,1380,1390,1395
1370 GCOSTRAN=11.17*TPOW ! GOTO 1400
1380 GCOSTRAN=5.58*TPOW ! GOTO 1400
1390 GCOSTRAN=4.65*TPOW ! GOTO 1400
1395 GCOSTRAN=5.4*TPOW
1400 REM
1410 WBV=CURBWT-WB-MOTWT-ENGWT-CONWT-TRANWT-ETRANWT-GTRANWT
1420 BI=(1+RINTR)^YEAR
1430 DI=(1+RDISR)^YEAR
1440 CI=BI/DI
1450 BVCPKG=6.95
1460 BVC=(WBV*BVCPKG)+CACC
1470 AUP=1.5
1480 REM   ENGINE COST
1490 ENGC=1.5*240*EPOW^.33 ! IF FTYP=2 THEN ENGC=1.5*260*EPOW^.33
1495 REM MOTOR AND CONTROLLER COST
1500 CCON=45*CKW! CMOT=19*MKW
1510 IF MTYP=2 THEN CCON=90*CKW ! CMOT=26.5*MKW
1515 IF MTYP=3 THEN CCON=62.5*CKW ! CMOT=79*MKW
1517 IF VTYP=3 THEN GO 2270
1520 REM BATTERY OEM COST ($1983)
1530 IF BATT$="AL-AIR" THEN GOTO 1850
1540 IF BATT$="NI-ZN2.0" THEN CWBT=130*(54/1000)*WB
1550 IF BATT$="PBAC/AD1.0" THEN CWBT=(43*(45/1000)*WB)+(8.7*(120/1000)*WB)+400
1560 IF BATT$="PBAC/AD2.1" THEN CWBT=(43*(43/1000)*WB)+(8.7*(135/1000)*WB)+400
1570 IF BATT$="PBAC/AD2.4" THEN CWBT=(43*(41/1000)*WB)+(8.7*(135/1000)*WB)+400
1580 IF BATT$="PBAC/AD3.3" THEN CWBT=(43*(38/1000)*WB)+(8.7*(145/1000)*WB)+400
1590 IF BATT$="PB-AC/BIPL" THEN CWBT=(80*(50/1000)*WB)
1600 IF BATT$="NI-FE1.0" THEN CWBT=(100*(56/1000)*WB)+(12*(120/1000)*WB)+800
1610 IF BATT$="NI-FE2.1" THEN CWBT=(100*(54/1000)*WB)+(12*(141/1000)*WB)+800
1620 IF BATT$="NI-FE2.4" THEN CWBT=(100*(52/1000)*WB)+(12*(141/1000)*WB)+800
1630 IF BATT$="NI-FE3.3" THEN CWBT=(100*(48/1000)*WB)+(12*(160/1000)*WB)+800
1640 IF BATT$="ZN-BR2/1.0" THEN CWBT=(20*(67/1000)*WB)+(10*(83/1000)*WB)+700
1650 IF BATT$="ZN-BR2/2.1" THEN CWBT=(20*(48/1000)*WB)+(10*(115/1000)*WB)+700
1660 IF BATT$="ZN-BR2/2.4" THEN CWBT=(20*(49/1000)*WB)+(10*(135/1000)*WB)+700
1670 IF BATT$="ZN-BR2/[illegible]" THEN CWBT=(20*(4[illegible]/1000)*WB)+(10*(150/1000)*WB)+700
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1680 IF BATT$="ZN-CL2/1.0" THEN CWBT=(10*(89/1000)*WB)+(45*(86/1000)*WB)+1150
1690 IF BATT$="ZN-CL2/2.1" THEN CWBT=(10*(54/1000)*WB)+(45*(110/1000)*WB)+1150
1700 IF BATT$="ZN-CL2/2.4" THEN CWBT=(10*(54/1000)*WB)+(45*(127/1000)*WB)+1150
1710 IF BATT$="ZN-CL2/3.3" THEN CWBT=(10*(42/1000)*WB)+(45*(130/1000)*WB)+1150
1720 IF BATT$="FE-AIR1.0" THEN CWBT=(8*(109/1000)*WB)+(25*(110/1000)*WB)+700
1730 IF BATT$="FE-AIR2.1" THEN CWBT=(8*(68/1000)*WB)+(25*(140/1000)*WB)+700
1740 IF BATT$="FE-AIR2.4" THEN CWBT=(8*(68/1000)*WB)+(25*(157/1000)*WB)+700
1750 IF BATT$="FE-AIR3.3" THEN CWBT=(8*(52/1000)*WB)+(25*(165/1000)*WB)+700
1760 IF BATT$="LI-FE-S1.0" THEN CWBT=(70*(102/1000)*WB)+(10*(161/1000)*WB)+750
1770 IF BATT$="LI-FE-S3.3" THEN CWBT=(70*(81/1000)*WB)+(10*(175/1000)*WB)+750
1780 IF BATT$="LI-FE-S2.1" THEN CWBT=(70*(81/1000)*WB)+(10*(165/1000)*WB)+750
1790 IF BATT$="LI-FE-S2.4" THEN CWBT=(70*(71/1000)*WB)+(10*(165/1000)*WB)+750
1800 IF BATT$="NA-S1.0" THEN CWBT=(25*(121/1000)*WB)+(45*(148/1000)*WB)+1000
1810 IF BATT$="NA-S2.1" THEN CWBT=(25*(87/1000)*WB)+(45*(199/1000)*WB)+1000
1820 IF BATT$="NA-S2.4" THEN CWBT=(25*(83/1000)*WB)+(45*(224/1000)*WB)+1000
1830 IF BATT$="NA-S3.3" THEN CWBT=(25*(73/1000)*WB)+(45*(244/1000)*WB)+1000
1840 GOTO 1870
1850 BKW=(157*WB)/1000
1860 CWBT=42*BKW
1870 REM BATTERY COST ($1982)
1880 CWBT=(1.5*CWBT)/(1+RDISR)
1890 IF BATT$="PBAC/AD1.0" THEN CWBTH=1.16*CWBT
1900 IF BATT$="PBAC/AD2.1" THEN CWBTH=1.35*CWBT
1910 IF BATT$="PBAC/AD2.4" THEN CWBTH=1.2*CWBT
1920 IF BATT$="PBAC/AD3.3" THEN CWBTH=1.27*CWBT
1930 IF BATT$="PB-AC/BIPL" THEN CWBTH=1.5*CWBT
1940 IF BATT$="NI-FE1.0" THEN CWBTH=.9099999*CWBT
1950 IF BATT$="NI-FE2.1" THEN CWBTH=.87*CWBT
1960 IF BATT$="NI-FE2.4" THEN CWBTH=.9000001*CWBT
1970 IF BATT$="NI-FE3.3" THEN CWBTH=1.01*CWBT
1980 IF BATT$="NI-ZN2.0" THEN CWBTH=1.1*CWBT
1990 IF BATT$="ZN-BR2/1.0" THEN CWBTH=1.59*CWBT
2000 IF BATT$="ZN-BR2/2.1" THEN CWBTH=2.02*CWBT
2010 IF BATT$="ZN-BR2/2.4" THEN CWBTH=1.72*CWBT
2020 IF BATT$="ZN-BR2/3.3" THEN CWBTH=1.83*CWBT
2030 IF BATT$="ZN-CL2/1.0" THEN CWBTH=1.24*CWBT
2040 IF BATT$="ZN-CL2/2.1" THEN CWBTH=1.04*CWBT
2050 IF BATT$="ZN-CL2/2.4" THEN CWBTH=1.04*CWBT
2060 IF BATT$="ZN-CL2/3.3" THEN CWBTH=1.01*CWBT
2070 IF BATT$="FE-AIR1.0" THEN CWBTH=1.83*CWBT
2080 IF BATT$="FE-AIR2.1" THEN CWBTH=2.57*CWBT
2090 IF BATT$="FE-AIR2.4" THEN CWBTH=1.83*CWBT
2100 IF BATT$="FE-AIR3.3" THEN CWBTH=2.03*CWBT
2110 IF BATT$="NA-S1.0" THEN CWBTH=1.36*CWBT
2120 IF BATT$="NA-S2.1" THEN CWBTH=1.24*CWBT
2130 IF BATT$="NA-S2.4" THEN CWBTH=.95*CWBT
2140 IF BATT$="NA-S3.3" THEN CWBTH=.9099999*CWBT
2150 IF BATT$="LI-FE-S1.0" THEN CWBTH=1.28*CWBT
2160 IF BATT$="LI-FE-S2.1" THEN CWBTH=.93*CWBT
2170 IF BATT$="LI-FE-S2.4" THEN CWBTH=1.19*CWBT
2180 IF BATT$="LI-FE-S3.3" THEN CWBTH=.98*CWBT
2190 IF BATT$="AL-AIR" THEN CWBTH=1.5*CWBT
2200 REM LOW AND HIGH BARTTERY COST
2210 IF CWBTH>CWBT THEN GOTO 2270
2230 XXX=CWBT
2240 CWBT=CWBTH
2260 CWBTH=XXX
2270 REM  INITIAL COST
2280 INIT=CWBT+BVC+CMOT+CCON+ECOSTRAN+ENGC+GCOSTRAN+COSTRAN
2290 INITH=CWBTH+BVC+CMOT+CCON+ECOSTRAN+ENGC+GCOSTRAN+COSTRAN
2295 IF VTYP=3 THEN GO 3040
2300 REM  REPLACEMENT BATTERIES
2310 IF BATT$="AL-AIR" GOTO 2440
```

```
2320 RBATYR=(CYCB*DDCO*10)/(ADOD*365*BLIF)
2330 LI=1/((1+RDISR)^RBATYR)
2340 TI=((1+RINTR)^RBATYR)
2350 RBAT=((AUOD*365*BLIF)/(DDCO*CYCB))-1
2360 IF RBAT>0 GOTO 2380
2362 RBAT=0
2364 IRBAT=0
2366 GOTO 2390
2370 REM THIS TAKES FRACTIONAL BATTERIES AND MAKE THEM WHOLE NUMBERS FOR BATTERY
     REPLACEMENT. THE DIFFERENCE BETWEEN THE WHOLE NUMBER AND THE FRACTION IS CO
     NSIDERED AS BATTERY SALVAGE
2380 IRBAT=CINT(RBAT+.5)
2390 DRBAT=IRBAT-RBAT
2400 IF DRBAT<0 THEN DRBAT=0
2410 CWRB=IRBAT*CWBT*TI*LI
2420 CWRBH=IRBAT*CWBTH*LI*TI
2430 GOTO 2460
2440 CWRB=2*31*BKW
2450 GOTO 3040
2460 REM DETERMINATION OF BATTERY MATERIAL SALVAGE COST PER KWH
2470 IF BATT$="PBAC/AD1.0" OR BATT$="PBAC/AD2.1" THEN MCPKWH=1.66
2480 IF BATT$="PBAC/AD2.4" OR BATT$="PBAC/AD3.3" THEN MCPKWH=1.66
2490 IF BATT$="PB-AC/BIPL" THEN MCPKWH=1.66
2500 IF BATT$="NI-FE1.0" OR BATT$="NI-FE2.1" THEN MCPKWH=6.56
2510 IF BATT$="NI-FE2.4" OR BATT$="NI-FE3.3" THEN MCPKWH=6.56
2520 IF BATT$="ZN-BR2/1.0" OR BATT$="ZN-BR2/2.1" THEN MCPKWH=2
2530 IF BATT$="ZN-BR2/2.4" OR BATT$="ZN-BR2/3.3" THEN MCPKWH=2
2540 IF BATT$="ZN-CL2/1.0" OR BATT$="ZN-CL2/2.1" THEN MCPKWH=0
2550 IF BATT$="ZN-CL2/2.4" OR BATT$="ZN-CL2/3.3" THEN MCPKWH=0
2560 IF BATT$="FE-AIR1.0" OR BATT$="FE-AIR2.1" THEN MCPKWH=0
2570 IF BATT$="FE-AIR2.4" OR BATT$="FE-AIR3.3" THEN MCPKWH=0
2580 IF BATT$="LI-FE-S1.0" OR BATT$="LI-FE-S2.1" THEN MCPKWH=2
2590 IF BATT$="LI-FE-S2.4" OR BATT$="LI-FE-S3.3" THEN MCPKWH=2
2600 IF BATT$="NA-S1.0" OR BATT$="NA-S2.1" THEN MCPKWH=0
2610 IF BATT$="NA-S2.4" OR BATT$="NA-S3.3" THEN MCPKWH=0
2620 IF BATT$="NI-ZN2.0" THEN MCPKWH=10.23
2625 IF BATT$="AL-AIR" THEN MCPKWH=0
2630 REM SPECIFIC ENERGY VALUES ARE SUBSTITUTED IN THE FOLLOWING EQUATIONS
2640 IF BATT$="PBAC/AD1.0" THEN KWHR=(45/1000)*WB
2650 IF BATT$="PBAC/AD2.1" THEN KWHR=(43/1000)*WB
2660 IF BATT$="PBAC/AD2.4" THEN KWHR=(41/1000)*WB
2670 IF BATT$="PBAC/AD3.3" THEN KWHR=(38/1000)*WB
2680 IF BATT$="PB-AC/BIPL" THEN KWHR=(50/1000)*WB
2690 IF BATT$="NI-FE1.0" THEN KWHR=(56/1000)*WB
2700 IF BATT$="NI-FE2.1" THEN KWHR=(54/1000)*WB
2710 IF BATT$="NI-FE2.4" THEN KWHR=(52/1000)*WB
2720 IF BATT$="NI-FE3.3" THEN KWHR=(48/1000)*WB
2730 IF BATT$="ZN-BR2/1.0" THEN KWHR=(67/1000)*WB
2740 IF BATT$="ZN-BR2/2.1" THEN KWHR=(48/1000)*WB
2750 IF BATT$="ZN-BR2/2.4" THEN KWHR=(49/1000)*WB
2760 IF BATT$="ZN-BR2/3.3" THEN KWHR=(40/1000)*WB
2770 IF BATT$="ZN-CL2/1.0" THEN KWHR=(89/1000)*WB
2780 IF BATT$="ZN-CL2/2.1" THEN KWHR=(54/1000)*WB
2790 IF BATT$="ZN-CL2/2.4" THEN KWHR=(54/1000)*WB
2800 IF BATT$="ZN-CL2/3.3" THEN KWHR=(42/1000)*WB
2810 IF BATT$="FE-AIR1.0" THEN KWHR=(109/1000)*WB
2820 IF BATT$="FE-AIR2.1" THEN KWHR=(68/1000)*WB
2830 IF BATT$="FE-AIR2.4" THEN KWHR=(68/1000)*WB
2840 IF BATT$="FE-AIR3.3" THEN KWHR=(52/1000)*WB
2850 IF BATT$="LI-FE-S1.0" THEN KWHR=(102/1000)*WB
2860 IF BATT$="LI-FE-S2.1" THEN KWHR=(81/1000)*WB
2870 IF BATT$="LI-FE-S2.4" THEN KWHR=(81/1000)*WB
2880 IF BATT$="LI-FE-S3.3" THEN KWHR=(71/1000)*WB
```

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```
2890 IF BATT$="NA-S1.0" THEN KWHR=(121/1000)*WB
2900 IF BATT$="NA-S2.1" THEN KWHR=(87/1000)*WB
2910 IF BATT$="NA-S2.4" THEN KWHR=(83/1000)*WB
2920 IF BATT$="NA-S3.3" THEN KWHR=(73/1000)*WB
2930 IF BATT$="NI-ZN2.0" THEN KWHR=(60/1000)*WB
2940 REM BATTERY SALVAGE VALUE IS THE SUM OF SALVAGE FROM REPLACEMENT BATTERIES
     AND BATTERY SALVAGE MATERIAL
2950 SVB1=MCPKWH*TI*KWHR*LI
2960 SVBH1=(MCPKWH*TI*KWHR)*LI
2970 IF IRBAT=2 THEN TRBATYR=2*RBATYR:GOTO 2990
2980 GOTO 3035
2990 SI=(1+RINTR)^TRBATYR
3000 ZI=1/((1+RDISR)^TRBATYR)
3010 IF TRBATYR<10 THEN SVB2=(MCPKWH*SI*KWHR)*ZI
3020 IF TRBATYR>10 THEN GOTO 3035
3030 SVBH2=(MCPKWH*SI*KWHR)*ZI
3035 SVB=SVB1+SVB2
3036 SVBH=SVBH1+SVBH2
3038 REM ALL OPERATING COSTS ARE DISCOUNTED TO PRESENT VALUES
3040 REM REPAIRS AND MAINTENANCE
3050 TKM=YEAR*KMYR
3060 IF VTYP=2 THEN MICE=0:GOTO 3080
3070 MICE=136.22
3080 ME=81.73001
3090 RPM= (ME+(1.14/100*KMYR*EOLY*MFAC))+(MICE+(1.91/100*KMYR*RICE))
3100 RPMN=0
3110 FOR N=1 TO YEAR
3120 TEMP1=RPM*CI
3130 RPMN=RPMN+TEMP1
3140 NEXT N
3150 IF VTYP=2 THEN MICE=0:GOTO 3170
3160 MICE =131.11
3170 ME=78.67
3180 IF NPAS=5 THEN RPM= (ME+(1.23/100*KMYR*EOLY*MFAC))+(MICE+(2.05/100*KMYR*RIC
E))
3190 RPMN=0
3200 FOR N=1 TO YEAR
3210 TEMP2=RPM*CI
3220 RPMN=RPMN+TEMP2
3230 NEXT N
3240 REM   REPLACEMENT TIRES
3250 RTKM=TKM-64374!
3260 RTIR=(RTKM*(368.74+(.18086*CURBWT))/(128748!))
3270 REM  INSURANCE
3280 INSR=0
3290 FOR N=1 TO YEAR
3300 TEMP3=243*CI
3310 INSR=INSR+TEMP3
3320 NEXT N
3330 INSR=INSR+748
3340 IF NPAS=5 THEN GOTO 3345
3345 INSR=0
3350 FOR N=1 TO YEAR
3360 TEMP4=256*CI
3370 INSR=INSR+TEMP4
3380 NEXT N
3390 INSR=INSR+919
3400 REM GARAGING, PARKING AND TOLL
3410 PTE=0
3420 FOR N=1 TO YEAR
3430 TEMP5=78.25*CI
3440 PTE=PTE+TEMP5
3450 NEXT N
```

```
3460 REM  TITLE, REGISTRATION
3470 TRLE=0
3480 FOR N=1 TO YEAR
3490 TEMP7=20*CI
3500 TRLE=TRLE+TEMP7
3510 NEXT N
3520 TRLE=TRLE+(.05*INIT)
3530 TRLEH=0
3540 FOR N=1 TO YEAR
3550 TEMP8=20*CI
3560 TRLEH=TRLEH+TEMP8
3570 NEXT N
3580 TRLEH=TRLEH+(.05*INITH)
3590 REM  FUEL AND OIL COST
3600 CFU=AFUS*PFUEL*1.03
3610 CFUL=0
3620 CFU=AFUS*PFUEL*1.03
3630 FOR N=1 TO YEAR
3640 TEMP9=CFU*CI
3650 CFUL=CFUL+TEMP9
3660 NEXT N
3680 REM ELECTRICITY COST
3690 CEL=AELC*PELEC
3700 CELE=0
3720 FOR N=1 TO YEAR
3730 TEMP10=CEL*CI
3740 CELE=CELE+TEMP10
3745 IF BATT$="AL-AIR" THEN ANOD=.0625*KMYR*CI
3747 IF BATT$="AL-AIR" THEN CELE=CELE+ANOD
3750 NEXT N
3760 REM   ANNUAL PRINCIPAL  AND INTEREST PAYMENT
3770 APINT=.8*(INIT)*((RINTR*(1+RINTR)^FYEAR)/((1+RINTR)^FYEAR-1))
3780 FI=((1+RDISR)^FYEAR-1)
3790 OI=(RDISR*(1+RDISR)^FYEAR)
3800 PAPINT=APINT*FI/OI
3810 APINTH=.8*(INITH)*((RINTR*(1+RINTR)^FYEAR)/((1+RINTR)^FYEAR-1))
3820 PAPINTH=APINTH*FI/OI
3830 GOTO 3850
3840 REM
3850 REM   OPERATING COSTS
3860 OPER=CELE+CFUL+TRLE+PTE+INSR+RTIR+RPMN+CWRB+PAPINT
3870 OPERH=CELE+CFUL+TRLEH+PTE+INSR+RTIR+RPMN+CWRB+PAPINTH
3880 DPML=.2*INIT
3890 DPMH=.2*INITH
3895 IF VTYP=3 THEN GOTO 3932
3900 NBAT=(ADOD*365*BLIF)/(DDCO*CYCB)
3902 IF NBAT=<1 THEN DNBAT=0:GOTO 3932
3910 INBAT=CINT(NBAT+.5)
3920 DNBAT=INBAT-NBAT
3930 IF DNBAT<0 THEN DNBAT=0
3932 REM
3940 PI=1/((1+RDISR)^YEAR)
3950 SVV=(SLBV*(INIT-CWBT)+(CWBT*BI*DNBAT))*PI
3960 SVVH=(SLBV*(INITH-CWBTH)+(CWBTH*BI*DNBAT))*PI
3970 TTL=DPML+OPER-SVV-SVB1-SVB2
3980 TTLH=DPMH+OPERH-SVVH-SVBH1-SVBH2
3990 REM CALCULATIONS COMPLETE
4000 FORMATO$="\"+SPACE$(24)+"\"
4010 FORMAT1$="#####.## ##.###  "
4020 REM
4030 REM ** PRINT HEADER INFORMATION.
4040 REM
```

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```
4060 I=(80-LEN(PHD$))/2
4070 LPRINT : LPRINT SPACE$(I);PHD$;SPACE$(10);DATE$
4080 LPRINT : LPRINT SPACE$(33);"*--INPUTS--*" : LPRINT
4090 LPRINT " GENERAL --";TAB(40);"YEAR:     ";IDOL
4100 LPRINT "VEHICLE SIZE:  ";PASS$;TAB(40);
4110 LPRINT "REAL INTEREST RATE:  ";RINTR*100;"% "
4120 LPRINT "CURB WEIGHT: ";CURBWT;"KG";TAB(40);
4130 LPRINT "VEHICLE SALVAGE VALUE:    ";SLBV*100;"%"
4140 LPRINT"VEHICLE WEIGHT , WT:  ";WT
4150 LPRINT "LIFE:              ";TKM;"KM";TAB(40);"ACCESSORY COST:   $";CACC
4160 LPRINT
4170 LPRINT " BATTERY --";TAB(40);"NAME:   ";BATT$
4180 LPRINT "BATTERY WEIGHT:   ";WB;"KG";TAB(40);
4190 LPRINT "BATTERY CYCLE LIFE:  ";CYCB
4200 LPRINT "ELECTRICITY COST:   ";PELEC;"$/KW-H";TAB(40);
4210 LPRINT "MAXIMUM SHELF LIFE:   ";BLIF;"YEARS"
4220 LPRINT "AVERAGE DAILY DEPTH OF DISCHARGE: ";ADOD;TAB(40);
4230 LPRINT "DEPTH OF A DEEP DISCHARGE: ";DDCG
4240 LPRINT "MAINTENANCE FACTOR:  ";MFAC
4250 LPRINT
4260 IF VTYP=2 THEN GOTO 4310
4270 LPRINT " ENGINE --";TAB(40);
4280 LPRINT "FUEL COST:   ";PFUEL;"$/L"
4290 LPRINT "TANK CAPACITY:   ";VGAS;"L";TAB(40);"FUEL TYPE:   ";FTYP$
4300 IF NTRAN=2 THEN GOTO 4350
4310 LPRINT "TRANSMISSION TYPE:  ";TRAN$;
4320 IF VTYP=2 THEN GOTO 4340
4330 LPRINT TAB(40);"RATED POWER:   ";EPOW;"KW"
4340 GOTO 4360
4350 LPRINT "ICE TRANSMISSION TYPE:  ";GTRAN$;TAB(40);"POWER:  ";TPOW;"KW"
4360 LPRINT
4370 LPRINT " MOTOR --"
4380 LPRINT "RATED POWER:          ";MKW;"KW";TAB(40)
4390 LPRINT "TYPE:           ";MTYP$
4400 LPRINT "CONTROLLER:         ";CKW;" KW"
4410 IF NTRAN=1 THEN GOTO 4430
4420 LPRINT "EV TRANSMISSION TYPE:   ";ETRAN$;TAB(40);"POWER:  ";ETKW;"KW"
4430 LPRINT
4440 LPRINT " DRIVING --";TAB(40);"AMOUNT:   ";KMYR;"KM/YEAR"
4450 IF VTYP=2 THEN GOTO 4490
4460 LPRINT "ICE FRACTIONAL RANGE:   ";RICE*100;"%";TAB(40);
4470 LPRINT "EV FRACTIONAL RANGE:   ";EOLY*100;"%"
4480 LPRINT "ANNUAL FUEL USE:   ";AFUS;" L";TAB(40);
4490 LPRINT "ANNUAL ELEC USE:   ";AELC;"KW-H"
4500 REM
4510 A=100/TKM
4520 REM ** PRINT OUTPUT INFORMATION.
4530 LPRINT : LPRINT TAB(32);"*-- OUTPUTS --*" : LPRINT : LPRINT
4540 LPRINT "COST ITEMS-"
4550 LPRINT TAB(24);
4560 LPRINT "       $     C/KM";
4570 LPRINT
4580 LPRINT USING FORMAT0$; "BASIC VEHICLE COST";
4590 LPRINT USING FORMAT1$; BVC;BVC*A
4600 IF VTYP=2 THEN GOTO 4650
4610 LPRINT USING FORMAT0$; "ENGINE COST";
4620 LPRINT USING FORMAT1$; ENGC;ENGC*A
4630 LPRINT USING FORMAT0$; "ICE TRANSMISSION COST";
4640 LPRINT USING FORMAT1$; GCOSTRAN;GCOSTRAN*A
4650 LPRINT USING FORMAT0$; "MOTOR COST";
4660 LPRINT USING FORMAT1$; CMOT;CMOT*A
4670 LPRINT USING FORMAT0$; "CONTROLLER COST";
4680 LPRINT USING FORMAT1$; CCON;CCON*A
```

```
4690 IF NTRAN=1 THEN GOTO 4730
4700 LPRINT USING FORMAT0$; "EV TRANSMISSION COST";
4710 LPRINT USING FORMAT1$; ECOSTRAN;ECOSTRAN*A
4720 GOTO 4750
4730 LPRINT USING FORMAT0$; "EV TRANSMISSION COST";
4740 LPRINT USING FORMAT1$; COSTRAN;COSTRAN*A
4750 LPRINT USING FORMAT0$; "BATTERY     LOW";
4760 LPRINT USING FORMAT1$; CWBT;CWBT*A,
4770 LPRINT  "HIGH";
4780 LPRINT USING FORMAT1$; CWBTH;CWBTH*A
4790 LPRINT TAB(28);
4800 LPRINT "------- ------   ";
4810 LPRINT
4820 LPRINT "INITIAL COST     LOW      ";
4830 LPRINT USING FORMAT1$; INIT;INIT*A,
4840 LPRINT  "HIGH";
4850 LPRINT USING FORMAT1$; INITH;INITH*A
4860 LPRINT "DOWNPAYMENT     LOW        ";
4870 LPRINT USING FORMAT1$; DPML;DPML*A,
4880 LPRINT  "HIGH";
4890 LPRINT USING FORMAT1$; DPMH;DPMH*A
4900 LPRINT : LPRINT
4910 LPRINT USING FORMAT0$; "REPLACEM'T BATTS LOW";
4920 LPRINT USING FORMAT1$; CWRB;CWRB*A,
4930 LPRINT  "HIGH";
4940 LPRINT USING FORMAT1$; CWRBH;CWRBH*A
4950 'LPRINT "Number:    ";IRBAT
4960 LPRINT USING FORMAT0$;"REPAIRS & MAINTENANCE";
4970 LPRINT USING FORMAT1$; RPMN;RPMN*A
4980 LPRINT USING FORMAT0$; "REPLACEMENT TIRES";
4990 LPRINT USING FORMAT1$; RTIR;RTIR*A
5000 LPRINT USING FORMAT0$; "INSURANCE";
5010 LPRINT USING FORMAT1$; INSR;INSR*A
5020 LPRINT USING FORMAT0$; "GARAGING,PARK, TOLL";
5030 LPRINT USING FORMAT1$; PTE;PTE*A
5040 LPRINT USING FORMAT0$; "TITLE, REG, LIC, LOW.";
5050 LPRINT USING FORMAT1$; TRLE;TRLE*A,
5060 LPRINT  "HIGH";
5070 LPRINT USING FORMAT1$; TRLEH;TRLEH*A
5080 IF VTYP=2 THEN GOTO 5110
5090 LPRINT USING FORMAT0$; "FUEL-OIL             ";
5100 LPRINT USING FORMAT1$; CFUL;CFUL*A
5110 LPRINT USING FORMAT0$; "ELECTRICITY         ";
5120 LPRINT USING FORMAT1$; CELE;CELE*A
5130 LPRINT USING FORMAT0$; "PRIN & INT LOW";
5140 LPRINT USING FORMAT1$; PAPINT;PAPINT*A,
5150 LPRINT  "HIGH";
5160 LPRINT USING FORMAT1$; PAPINTH;PAPINTH*A
5170 GOTO 5180
5180 LPRINT TAB(28);
5190 LPRINT "------- ------   ";
5200 LPRINT
5210 LPRINT "OPERATING COST  LOW       ";
5220 LPRINT USING FORMAT1$; OPER;OPER*A,
5230 LPRINT  "HIGH";
5240 LPRINT USING FORMAT1$; OPERH;OPERH*A
5250 LPRINT : LPRINT : LPRINT
5260 LPRINT USING FORMAT0$; "VEHICLE SALVAGE VALUE  LOW ";
5270 LPRINT USING FORMAT1$; SVV;SVV*A,
5280 LPRINT  "HIGH";
5290 LPRINT USING FORMAT1$; SVVH;SVVH*A
5300 LPRINT USING FORMAT0$; "BATTERY SALVAGE  LOW ";
```

```
5320 LPRINT  "HIGH";
5330 LPRINT USING FORMAT1$; SVBH;SVBH*A
5340 LPRINT
5350 LPRINT
5360 LPRINT "TOTAL LIFE CYCLE COST  LOW";
5370 LPRINT USING FORMAT1$; TTL;TTL*A.
5380 LPRINT  "HIGH";
5390 LPRINT USING FORMAT1$; TTLH;TTLH*A
5400 LPRINT CHR$(12) : LPRINT CHR$(27) + "6"
5410 LPRINT CHR$(27) + "4"
5420 END
```

Advanced Vehicle Energy Program (AVENERGY)

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CONTENTS

A. INTRODUCTION

Advanced Vehicle Energy Program (AVENERGY) is a computer program written in the IBM version of Microsoft Basic.

The purpose of the AVENERGY Program is for use in calculating such information as electrical energy expended, fuel consumed, and depths of discherges on various cycles of the 24-hour cycles. Information derived from the results of this program is used as part of the input into the Advanced Vehicle Cost Program (AVCOST). In its present form the program is interactive and it is designed to accept inputs from ELVEC and provide inputs into AVCOST.

B. INPUT AND OUTPUT

The following list is the input required to run the program.

1. Input

Type of vehicle (electric or hybrid)

Weight of vehicle

Weight of battery

Battery cycle life

Maximum depth of discharge

Fuel economy, both federal and highway, when using the internal combustion engine (ICE)

Energy consumption and range for each cycle

A representative distance travelled on each of twelve cycles per day and corresponding number of days in the year that cycle is used

The following is a list of the output from the program:

2. Output

Annual travel in miles

Annual travel in kilometers

Electric energy use in kW/h

Annual cycles expended

Fuel miles travelled

Electric miles travelled

Fraction of mileage on electric

Fraction of mileage on engine/ICE

Miles per gallon on federal and highway

Vehicle weight

Battery weight

Battery cycle life

Average daily depth of discharge for hybrid vehicle

Annual gasoline consumption

Liters of methanol

Gallons of methanol

C. ENERGY CALCULATIONS

The following are equations and calculations needed for energy and depth-of-discharge statistics.

1. Total Distance Travelled on any Cycle

The distance travelled on any cycle is given by

$$MILES = M \times DAYS$$

where

MILES = total distance travelled on any cycle

M = miles per day travelled

DAYS = number of days in the year travelled on a given cycle

2. Electrical Energy Used on any Cycle

The electrical energy used on each cycle is obtained by multiplying the energy per mile (Wh/mi) by the miles travelled on that cycle, as follows:

$$EL = WHPM \times MILES$$

where

WHPM = Watt hours per mile

MILES = Total distance travelled on any cycle

EL = Watt hours on that cycle

3. Depth of Discharge

The depth of discharge is calculated by using the relationship

$$DOD = M/RANGE$$

where

M = miles per day

RANGE = distance vehicle travels to zero state of charge

DOD = depth of discharge

$$\text{Average daily depth of discharge} = \frac{\text{total annual depth of discharge}}{365}$$

4. Battery Cycles per Year

The number of battery cycles per year on any specific driving cycle is given by:

$$CYCLES = DOD \times DAYS$$

where

CYCLES is the battery cycles per year; the other variables are as previously defined above.

5. Total Distance Travelled per Year

Total distance travelled in a year is the summation of the cumulative distance travelled on each cycle.

6. Total Electrical Energy

Total electrical energy usage is the summation of the energy used on each cycle.

7. Total Number of Battery Cycles

Total number of battery cycles is the summation of the battery cycles on each driving cycle.

8. Fraction of Mileage on ICE

This is the fraction of miles driven as an ICE vehicle on gas only and is given by

$$FUEL = G/D$$

where

G = the fuel miles driven on gas

D = the total distance in miles

9. Fraction of Mileage on Electric

This is the fraction of miles driven as electric car only and is given by

$$ENER = P/D$$

where

P = the mileage driven as electric

D = total distance in miles

10. Annual Travel

This is the sum of miles travelled on electric and that on the heat engine.

11. Amount of Fuel Used on Highway and Urban Cycles

Amount of fuel used on highway is given by

$$FC = DAYS \times GM/MPGH$$

where

DAYS = number of days in the year travelled on a given cycle

GM = miles per day on gas

MPGH = miles per gallon on highway

FC = total fuel used for highway driving

Amount of fuel used on urban cycle is given by

$$FC = DAYS \times GM/MPGU$$

where

FC = total fuel used for urban driving

MPGU = miles per gallon on urban

DAYS = number of days in the year travelled on a given cycle

12. Total Fuel Miles

This is the sum of the mileage on each of the cycles covered by the ICE vehicle.

13. Total Electric Miles

This is the sum of the mileage on each of the cycles covered by the vehicle when it runs on electric only. Note that:

gallons of methanol = 1.8 x gallons of gas

liters of methanol = 3.8 x gallons of methanol

D. SAMPLE TEST CASE

Three test cases follow: a five-passenger baseline ICE, a five-passenger, 400-km Metal Disulphide (Li-fe-S_2) all-electric, and a five-passenger, 400-km Lead Acid (Pb-Ac) hybrid vehicle. The input and output results are as shown.

ELECTRIC AND HYBRID VEHICLE COST MODEL

100-MI BIPOLAR 5-P EV 08-29-1984

—INPUTS—

GENERAL —
VEHICLE SIZE: 5-PASS
CURB WEIGHT: 1098 KG
VEHICLE WEIGHT , WT: 1634
LIFE: 131434.9 KM

YEAR: 1982
REAL INTEREST RATE: 10 %
VEHICLE SALVAGE VALUE: 10 %

ACCESSORY COST: $ 200

BATTERY —
BATTERY WEIGHT: 404 KG
ELECTRICITY COST: .05 $/KW-H
AVERAGE DAILY DEPTH OF DISCHARGE: .2217449

NAME: PB-AC/BIPL
BATTERY CYCLE LIFE: 750
MAXIMUM SHELF LIFE: 10 YEARS
DEPTH OF A DEEP DISCHARGE: .8

MAINTENANCE FACTOR: .5

TRANSMISSION TYPE: fixed ratio
MOTOR —
RATED POWER: 41.2 KW
CONTROLLER: 45.7 KW

TYPE: AC

DRIVING —
ANNUAL ELEC USE: 2128.121 KW-H

AMOUNT: 13143.49 KM/YEAR

— OUTPUTS —

COST ITEMS-

		$	C/KM			
BASIC VEHICLE COST		6868.21	5.226			
MOTOR COST		782.80	0.596			
CONTROLLER COST		2056.50	1.565			
EV TRANSMISSION COST		212.51	0.162			
BATTERY	LOW	2203.64	1.677	HIGH	3305.45	2.515
INITIAL COST	LOW	12123.65	9.224	HIGH	13225.47	10.062
DOWNPAYMENT	LOW	2424.73	1.845	HIGH	2645.09	2.012
REPLACEM'T BATTS	LOW	2203.64	1.677	HIGH	3305.45	2.515
REPAIRS & MAINTENANCE		1566.48	1.192			
REPLACEMENT TIRES		333.18	0.253			
INSURANCE		3479.00	2.647			
GARAGING, PARK, TOLL		782.50	0.595			
TITLE, REG, LIC,	LOW.	806.18	0.613	HIGH	861.27	0.655
ELECTRICITY		1064.06	0.810			
PRIN & INT	LOW	9698.92	7.379	HIGH	10580.38	8.050
OPERATING COST	LOW	19933.97	15.166	HIGH	20870.51	15.879
VEHICLE SALVAGE VALUE	LOW	1817.14	1.383	HIGH	2534.48	1.928
BATTERY SALVAGE	LOW	33.53	0.026	HIGH	33.53	0.026
TOTAL LIFE CYCLE COST	LOW	20508.02	15.603	HIGH	20947.59	15.938

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ELECTRIC AND HYBRID VEHICLE COST MODEL

5 PAX BASELINE ICE 100M 1992   07-18-1984

—INPUTS—

GENERAL —
VEHICLE SIZE: 5-PASS
CURB WEIGHT: 895 KG
VEHICLE WEIGHT , WT: 1031
LIFE: 132365.9 KM

YEAR: 1982
REAL INTEREST RATE: 10 %
VEHICLE SALVAGE VALUE: 10 %
ACCESSORY COST: $ 200

BATTERY —
BATTERY WEIGHT: 0 KG
ELECTRICITY COST: .05 $/KW-H
AVERAGE DAILY DEPTH OF DISCHARGE: .11
MAINTENANCE FACTOR: 1

NAME: XXX
BATTERY CYCLE LIFE: 750
MAXIMUM SHELF LIFE: 10 YEARS
DEPTH OF A DEEP DISCHARGE: .8

ENGINE —
TANK CAPACITY: 40 L
ICE TRANSMISSION TYPE: CVT

FUEL COST: .373 $/L
FUEL TYPE: METHANOL
POWER: 31 KW

MOTOR —
RATED POWER: 0 KW
CONTROLLER: 0 KW
EV TRANSMISSION TYPE: fixed ratio

TYPE: AC

DRIVING —
ICE FRACTIONAL RANGE: 100 %
ANNUAL FUEL USE: 1302 L

AMOUNT: 13236.59 KM/YEAR
EV FRACTIONAL RANGE: 0 %
ANNUAL ELEC USE: 0 KW-H

— OUTPUTS —

COST ITEMS-

		$	C/KM		$	C/KM
BASIC VEHICLE COST		5745.61	4.341			
ENGINE COST		1118.03	0.845			
ICE TRANSMISSION COST		346.27	0.262			
MOTOR COST		0.00	0.000			
CONTROLLER COST		0.00	0.000			
EV TRANSMISSION COST		0.00	0.000			
BATTERY	LOW	0.00	0.000	HIGH	0.00	0.000
INITIAL COST	LOW	7209.90	5.447	HIGH	7209.90	5.447
DOWNPAYMENT	LOW	1441.98	1.089	HIGH	1441.98	1.089
REPLACEM'T BATTS	LOW	0.00	0.000	HIGH	0.00	0.000
REPAIRS & MAINTENANCE		4707.69	3.557			
REPLACEMENT TIRES		280.22	0.212			
INSURANCE		3479.00	2.628			
GARAGING, PARK, TOLL		782.50	0.591			
TITLE, REG, LIC,	LOW.	560.50	0.423	HIGH	560.50	0.423
FUEL-OIL		5002.15	3.779			
ELECTRICITY		0.00	0.000			
PRIN & INT	LOW	5767.92	4.358	HIGH	5767.92	4.358
OPERATING COST	LOW	20579.98	15.548	HIGH	20579.98	15.548
VEHICLE SALVAGE VALUE	LOW	277.97	0.210	HIGH	277.97	0.210
BATTERY SALVAGE	LOW	0.00	0.000	HIGH	0.00	0.000
TOTAL LIFE CYCLE COST	LOW	21743.98	16.427	HIGH	21743.98	16.427

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ELECTRIC AND HYBRID VEHICLE COST MODEL

PB/ACID HYBRID 08-29-1984

--INPUTS--

GENERAL --
VEHICLE SIZE: 5-PASS
CURB WEIGHT: 1747 KG
VEHICLE WEIGHT , WT: 1883
LIFE: 166106.7 KM

YEAR: 1982
REAL INTEREST RATE: 10 %
VEHICLE SALVAGE VALUE: 10 %
ACCESSORY COST: $ 200

BATTERY --
BATTERY WEIGHT: 410 KG
ELECTRICITY COST: .05 $/KW-H
AVERAGE DAILY DEPTH OF DISCHARGE: .3336073

NAME: PBAC/AD3.3
BATTERY CYCLE LIFE: 750
MAXIMUM SHELF LIFE: 10 YEARS
DEPTH OF A DEEP DISCHARGE: .8

MAINTENANCE FACTOR: 1

ENGINE --
TANK CAPACITY: 40 L
ICE TRANSMISSION TYPE: CVT

FUEL COST: .373 $/L
FUEL TYPE: METHANOL
POWER: 52.7 KW

MOTOR --
RATED POWER: 47.5 KW
CONTROLLER: 52.7 KW
EV TRANSMISSION TYPE: fixed ratio

TYPE: AC

DRIVING --
ICE FRACTIONAL RANGE: 22.15058 %
ANNUAL FUEL USE: 486.0288 L

AMOUNT: 16610.67 KM/YEAR
EV FRACTIONAL RANGE: 74.3363 %
ANNUAL ELEC USE: 2635.126 KW-H

-- OUTPUTS --

COST ITEMS-

		$	C/KM			
BASIC VEHICLE COST		7267.10	4.375			
ENGINE COST		1331.99	0.802			
ICE TRANSMISSION COST		588.66	0.354			
MOTOR COST		902.50	0.543			
CONTROLLER COST		2371.50	1.428			
EV TRANSMISSION COST		245.06	0.148			
BATTERY	LOW	2164.30	1.303	HIGH	2748.66	1.655
INITIAL COST	LOW	14871.10	8.953	HIGH	15455.46	9.305
DOWNPAYMENT	LOW	2974.22	1.791	HIGH	3091.09	1.861
REPLACEM'T BATTS	LOW	4328.60	2.606	HIGH	5497.33	3.310
REPAIRS & MAINTENANCE		4289.90	2.583			
REPLACEMENT TIRES		541.03	0.326			
INSURANCE		3479.00	2.094			
GARAGING,PARK, TOLL		782.50	0.471			
TITLE, REG, LIC.	LOW.	943.56	0.568	HIGH	972.77	0.586
FUEL-OIL		1867.27	1.124			
ELECTRICITY		1317.56	0.793			
PRIN & INT	LOW	11896.88	7.162	HIGH	12364.37	7.444
OPERATING COST	LOW	29446.31	17.727	HIGH	29943.02	18.026
VEHICLE SALVAGE VALUE	LOW	2590.48	1.560	HIGH	3157.63	1.901
BATTERY SALVAGE	LOW	51.73	0.031	HIGH	51.73	0.031
TOTAL LIFE CYCLE COST	LOW	29778.33	17.927	HIGH	29824.75	17.955

GLOSSARY

ABBREVIATIONS AND ACRONYMS

BCL	battery-cycle life in cycles
CYCLES	cycle based on depth of discharges and days
D	total distance in miles
DAYS	number of days
DOD	depth of discharge
DODMX	maximum depth of discharge
EL	Watt hours
EM	miles per day on electric
ENER	fraction of mileage on electric
FC	total fuel used for urban or highway driving
FUEL	fraction of mileage on fuel
G	fuel miles
GALM	gallons of methanol
GAS	annual gasoline consumption in gallons
GM	miles per day on gas
K	cut-off range in miles
LITM	liters of methanol
M	miles per day
MILES	total distance travelled in miles on any cycle
MPGH	miles per gallon -- highway
MPGU	miles per gallon -- urban
P	miles on electric
RANGE	range in miles

VEH	vehicle type, electric or hybrid
WB	battery weight in kilograms
WC	vehicle curb weight in kilograms
WHPM	watt hour per mile
WC	vehicle curb weight in kilograms
X	total annual depth of discharge on all cycles

Advanced Vehicle Cost Program (AVCOST)

CONTENTS

A. INTRODUCTION

The Advanced Vehicle Cost Program (AVCOST) is a computer program written in the IBM version of Microsoft Basic for use in computing initial, operating, and life-cycle costs of advanced vehicles. It is being used for the evaluation of candidate vehicles in the Advanced Vehicle Assessment study as part of the work performed by the Jet Propulsion Laboratory (JPL) for the Electric and Hybrid Vehicle (EHV) Division of the U.S. Department of Energy (DOE). In its present form the program is interactive, and the user is prompted for various inputs. Other inputs into the program are from files that have been previously created after running AVSIZING and AVENERGY programs.

The advanced vehicles that could be used with the program are all-electric two-, four-, and five-passenger vehicles or vans and four- and five-passenger hybrid vehicles and corresponding baseline internal combustion engine (ICE) vehicles. In the following pages, input, output, cost calculations, and an example test case are presented.

B. INPUT AND OUTPUT

The following paragraphs list the input required for the program; a sample output is also included.

1. Input

Input into the program depends on whether the vehicle is all-electric, a hybrid vehicle, or a baseline ICE. Sample input into each type of vehicle is listed below:

a. Input: All-Electric

The page heading

The name of the battery

Enter 1 for hybrid, 2 for electric only, or 3 for ICE vehicle

Type the number of passengers as follows:

1 - Two-passenger

2 - Four-passenger, 250-mi

3 - Five-passenger, 250-mi

4 - Five-passenger, 100-mi

5 - Five-passenger, 150-mi

6 - Van

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Cost of electricity in ¢/kWh

Battery shelf life in years

Depth of a deep discharge (use cut-off DOD)

Vehicle maintenance factor--default=1

Vehicle life in years

Motor type: 1 for ac, 2 for dc brushless, and 3 for dc brush

Controller type: 1 for ac, 2 for dc brushless, and 3 for dc brush

Vehicle salvage value as percent of new

Percent real interest rate

Percent real discount rate

Number of years to finance over

b. Input: Hybrid

The page heading

The name of the battery

Enter 1 for hybrid, 2 for electric-only or 3 for ICE vehicles

Type the number of passengers as follows:

1 - Two-passenger

2 - Four-passenger, 250-mi

3 - Five-passenger, 250-mi

4 - Five-passenger, 100-mi

5 - Five-passenger, 150-mi

6 - Van

Cost of electricity in ¢/kWh

Battery shelf life in years

Depth of a deep discharge (use cut-off DOD)

Vehicle maintenance factor--default=1

Vehicle life in years

Motor type: 1 for ac, 2 for dc brushless, and 3 for dc brush

Controller type: 1 for ac, 2 for dc brushless, and 3 for dc brush

Vehicle salvage value as percent of new

Type 1 for gasoline fuel, 2 for diesel, 3 for methanol

Cost of fuel for 1992 in 1982$/liter

Percent real interest rate

Percent real discount rate

Number of years to finance over

c. Input: Baseline ICE

The page heading

Enter 1 for hybrid, 2 for electric, or 3 for ICE vehicle.

Type the number of passengers as follows:

1 - Two-passenger

2 - Four-passenger, 250-mi

3 - Five-passenger, 250-mi

4 - Five-passenger, 100-mi

5 - Five-passenger, 150-mi

6 - Van

Vehicle maintenance factor--default=1

Vehicle life in years

Vehicle salvage value as a percent

Type 1 for gasoline, 2 for diesel, 3 for methanol

Cost of fuel in 1992 in 1982$/liter

Percent real interest rate

Percent real discount rate

Number of years to finance over

The input is printed together with the output results as shown in the test case examples in Subsection D.

2. Output

Output results from the program, as well as the inputs into the program, are printed on the same page. This arrangement provides easy check on the input.

The output results from the program are categorized into initial, operating, and life-cycle costs. Initial cost is subdivided into basic vehicle, engine, electric transmission, motor, controller, engine transmission, and battery cost. Operating cost is subdivided into replacement batteries, repairs and maintenance, replacement tires, insurance, garage, park, toll, title, registration, license, fuel oil and electricity, and vehicle interest. Salvage value and life-cycle costs are also printed out. A sample output is as shown in the test-case examples for all-electric, hybrid, and a baseline ICE vehicle in Section D.

C. COST CALCULATIONS

The following paragraphs show the computation for initial, operating, and life-cycle costs.

1. Initial Cost

Initial cost is defined as the cost to the consumer. It is made up of the following costs: basic vehicle, engine, transmission, (one or two transmissions) motor, controller, and battery costs.

a. Basic Vehicle Cost. This cost is computed as the product of the weight of the basic vehicle and a cost per weight of the basic vehicle. The basic-vehicle weight is obtained by removing the battery, motor, engine, controller, and transmission from the vehicle curb weight.

Thus

Basic Vehicle Weight (WBV) = Curb weight (CURBWT)

- Battery weight (WB)

- Motor weight (MOTWT)

- Engine weight (ENGWT)

- Controller weight (CONWT)

- Electric transmission weight (TRANWT EV case)

- Electric transmission weight (ETRANWT HV case)

- Engine transmission weight (GTRANWT).

User inputs are curb weight and battery weight. The other weights are calculated as functions of the rated power as follows:

$$\text{Motor weight} = \frac{\text{Motor kW}}{0.49}$$

when a specific weight of 490 W/kg is assumed for ac (Volume II, Subsystems Assessment), 640 W/kg for dc brushless, and 220 W/kg for dc brush.

$$\text{Engine weight} = \frac{\text{Engine power kW}}{0.45}$$

when a specific weight of 450 W/kg is assumed for engine (see Volume II)

$$\text{Controller weight} = \frac{\text{Controller power kW}}{2.5}$$

when a specific weight of 2500 W/kg is assumed for ac, 875 W/kg for dc brushless, and 1470 W/kg for dc brush.

$$\text{Transmission weight} = \frac{\text{Power}}{1.1}\ \text{(CVT)}$$

when a specific weight of 1100 W/kg is assumed for Belt CVT (see Volume II)

$$\text{Transmission weight} = \frac{\text{Power*}}{1.42}\text{(fixed ratio)}$$

when a specific weight of 1420 W/kg is assumed for fixed-gear reduction (see Volume II)

$$\text{Transmission weight} = \frac{\text{Power*}}{1.06}\text{(4-speed manual)}$$

*Note that power is peak power.

when a specific weight of 1060 W/kg is assumed for 4-speed manual (see Volume II)

$$\text{Transmission weight} = \frac{\text{Power*}}{0.86}$$

when a specific weight of 860 W/kg is assumed for the 2-speed auto (see Volume II).

Basic Vehicle Cost (BVC) = basic vehicle weight (WBV)

x cost per kg of basic vehicle (BVCPKG)

+ accessory cost (CACC)

Basic vehicle cost (BVC) = WBV x BVCPKG + CACC

where

WBV = the basic vehicle weight calculated as shown above

BVCPKG = the cost per kg of basic vehicle weight. This is representative of the cost per kg of a 1981 Chevrolet Citation (Wayne Carrier, General Research Corporation). The cost of accessories is assumed to be $200.

b. Engine Cost. Engine cost is given by the following:

$$\text{Engine cost} = 1.5 \times 240 \times (\text{Engine Power in kW})^{0.33}$$
for gas engine from Volume II

$$1.5 \times 260 \times (\text{Engine Power in kW})^{0.33}$$
for diesel engine from Volume II

Engine maximum-rated power is an input
1.5 represents the mark-up from OEM cost to sale price

c. Transmission Cost. Transmission cost is a function of rated power. Transmission cost is related to the rated power by

Transmission cost = 11.17 x Power (CVT)

Transmission cost = 5.58 x Power (4-Speed)

*Note that power is peak power.

Transmission cost = 4.65 x Power (fixed ratio)

Transmission cost = 5.40 x Power (2-Speed Auto)

Transmission rated power is an input.

d. Motor Cost. Motor cost is given by

Motor cost = 19 x Motor Power kW (ac)

= 26.5 x Motor Power kW (dc brushless)

= 79 x Motor Power kW (dc brush)

Cost includes the mark-up of 1.5 (see Volume II)
Motor-rated power is an input.

e. Controller Cost. Controller cost is related to controller power by:

Controller cost = 45 x controller power kW for ac (see Volume II)

= 90 x controller power kW for dc brushless (see Volume II)

= 62.5 x controller power, kW dc brushless (see Volume II)

The cost for the controller includes the mark-up of 1.5.
Controller-rated power is an input.

f. Battery Cost. Battery cost is calculated using Symon's Equation of the form:

Cost (1983$) = A x kWh + B x kW + C

where A is the specific energy specified, B is the specific power specified, and C is a constant for the battery.

Battery cost for each battery type and design is listed in the program. The high battery cost represents the upper-bound cost of that battery.

As mentioned before, initial cost is the sum of the following cost: basic vehicle, engine, transmission, (one or two transmissions) motor, controller, and battery.

2. Operating Cost

Operating costs include the following: replacement batteries, replacement tires, insurance, repairs and maintenance, insurance, garage, parking, toll, title, registration, license, fuel and oil, electricity, and equivalent road tax. Each one of these is as discussed below. It may be noted that each of these annual values is discounted to present values.

a. Replacement Battery Cost. The cost of replacement batteries is the product of the unit cost of battery and the number of replacement batteries. The number of replacement batteries may be a fraction. In such a case the price of a whole battery is determined and the difference between the whole number and fraction is taken as battery salvage. The appropriate discount factor is applied.

b. Repairs and Maintenance Cost. For all cars except five-passenger cars, repairs and maintenance cost is given by

$$RPM = [81.73 + (\frac{1.14}{100} * KMYR * EOLY * MFAC)] + [MICE + (\frac{1.91}{100} * KMYR * RICE)]$$

For five-passenger cars

$$RPM = [78.67 + (\frac{1.23}{100} * KMYR * EOLY * MFAC)] + [MICE + (\frac{2.05}{100} * KMYR * RICE)]$$

where

MFAC = maintenance factor

EOLY = decimal fraction of operation time with electric propulsion operating

RICE = decimal fraction of operating time with ICE propulsion operating

The appropriate discount factor is applied.

c. Replacement Tires.

$$RTIR = [RTKM * (368.74 + (0.18086 * CURBWT)/(128748)]$$

where

RTIR = total cost of replacement tires over the vehicle life

RTKM = TKM - 64374

CURBWT = curb weight of the vehicle

TKM = vehicle life in km or total km driven over the vehicle life.

The appropriate discount factors at the times of replacement are applied.

d. Insurance.

$$\begin{aligned} INSR &= 748 + 243\ CI \text{ for 2-, 4-passenger and vans} \\ &= 919 + 256\ CI \text{ for 5-passenger} \end{aligned}$$

where

INSR = total cost of insurance over the vehicle life

CI = discount factor

e. Garage, Parking, and Toll.

$$PTE = 78.25 * CI$$

where

PTE = total cost of garaging, parking, toll, etc. over the vehicle life

CI = discount factor

f. Title, Registration, and License.

$$TRLE = 20 * CI + (0.05 * INIT)$$

where

TRLE = total cost of title, registration, license, etc. over the vehicle life

CI = discount factor

INIT = initial cost of the vehicle

g. Fuel and Oil.

$$CFUL = AFUS*PFUEL*1.03*CI$$

where

CFUL = total cost of fuel and oil over the ICE or hybrid vehicle life

AFUS = annual fuel use in liters

PFUEL = cost of fuel in $/liters

CI = discount factor

The factor of 1.03 is used to allow for the cost of oil rather than just the cost of gas or diesel.

h. Electricity Cost:

$$CELE = AELC*PELEC*CI$$

where

CELE = total cost of electricity over the vehicle life

PELEC = electricity price in ¢ per kWh

AELC = annual electricity use kWh

CI = discount factor

i. Annual Principal and Interest Payment. After the initial cost of the vehicle has been calculated, a down payment of 20 percent is assumed. The difference is capitalized over the life of the vehicle and added to the annual operating costs. This annual cost is calculated using

$$APINT = 0.8*INIT \left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$$

where

APINT = the annual principal and interest payment

i = interest rate

n = vehicle life

INIT = initial cost of the vehicle

Total operating cost is the sum of the costs of replacement batteries, repairs and maintenance, replacement tires, insurance, garage, parking, tolls, title, registration, license, fuel and oil, electricity, and annual principal and interest payment. Salvage value is made up of salvage from vehicle and from battery material.

Total life-cycle cost is the sum of initial cost and operating cost, less salvage value.

D. SAMPLE TEST CASE

Three test cases are presented below:

A 5-passenger baseline ICE, a 5-passenger 400-km lithium metal disulphide (Li-fe-S_2) all-electric, and a 5-passenger 400-km lead acid (Pb-Ac) hybrid vehicles. The input and output results are as shown.

ELECTRIC AND HYBRID VEHICLE COST MODEL

5 PAX BASELINE ICE 250M 07-18-1984

—INPUTS—

GENERAL —
VEHICLE SIZE: 5-PASS
CURB WEIGHT: 895 KG
VEHICLE WEIGHT , WT: 1031
LIFE: 166106 KM

YEAR: 1982
REAL INTEREST RATE: 10 %
VEHICLE SALVAGE VALUE: 10 %
ACCESSORY COST: $ 200

BATTERY —
BATTERY WEIGHT: 0 KG
ELECTRICITY COST: .05 $/KW-H
AVERAGE DAILY DEPTH OF DISCHARGE: 1
MAINTENANCE FACTOR: 1

NAME: XX
BATTERY CYCLE LIFE: 1
MAXIMUM SHELF LIFE: 10 YEARS
DEPTH OF A DEEP DISCHARGE: .8

ENGINE —
TANK CAPACITY: 40 L
ICE TRANSMISSION TYPE: CVT

FUEL COST: .373 $/L
FUEL TYPE: METHANOL
POWER: 31 KW

MOTOR —
RATED POWER: 0 KW
CONTROLLER: 0 KW
EV TRANSMISSION TYPE: fixed ratio

TYPE: AC

DRIVING —
ICE FRACTIONAL RANGE: 100 %
ANNUAL FUEL USE: 1610 L

AMOUNT: 16610.6 KM/YEAR
EV FRACTIONAL RANGE: 0 %
ANNUAL ELEC USE: 0 KW-H

— OUTPUTS —

COST ITEMS-

		$	C/KM			$	C/KM
BASIC VEHICLE COST		5745.61	3.459				
ENGINE COST		1116.03	0.673				
ICE TRANSMISSION COST		346.27	0.208				
MOTOR COST		0.00	0.000				
CONTROLLER COST		0.00	0.000				
EV TRANSMISSION COST		0.00	0.000				
BATTERY	LOW	0.00	0.000	HIGH		0.00	0.000
INITIAL COST	LOW	7209.90	4.341	HIGH		7209.90	4.341
DOWNPAYMENT	LOW	1441.98	0.868	HIGH		1441.98	0.868
REPLACEM'T BATTS	LOW	0.00	0.000	HIGH		0.00	0.000
REPAIRS & MAINTENANCE		5352.12	3.222				
REPLACEMENT TIRES		419.27	0.252				
INSURANCE		3479.00	2.094				
GARAGING,PARK, TOLL		782.50	0.471				
TITLE, REG, LIC,	LOW.	560.50	0.337	HIGH		560.50	0.337
FUEL-OIL		6185.46	3.724				
ELECTRICITY		0.00	0.000				
PRIN & INT	LOW	5767.92	3.472	HIGH		5767.92	3.472
OPERATING COST	LOW	22546.77	13.574	HIGH		22546.77	13.574
VEHICLE SALVAGE VALUE	LOW	277.97	0.167	HIGH		277.97	0.167
BATTERY SALVAGE	LOW	0.00	0.000	HIGH		0.00	0.000
TOTAL LIFE CYCLE COST	LOW	23710.78	14.274	HIGH		23710.78	14.274

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ELECTRIC AND HYBRID VEHICLE COST MODEL

250-MI LI/FES 5-P EV 08-29-1984

—INPUTS—

GENERAL —
VEHICLE SIZE: 5-PASS
CURB WEIGHT: 1804 KG
VEHICLE WEIGHT , WT: 1940
LIFE: 166106.7 KM

YEAR: 1982
REAL INTEREST RATE: 10 %
VEHICLE SALVAGE VALUE: 10 %
ACCESSORY COST: $ 200

BATTERY —
BATTERY WEIGHT: 615 KG
ELECTRICITY COST: .05 $/KW-H
AVERAGE DAILY DEPTH OF DISCHARGE: .1008848

NAME: LI-FE-61.0
BATTERY CYCLE LIFE: 750
MAXIMUM SHELF LIFE: 10 YEARS
DEPTH OF A DEEP DISCHARGE: .8

MAINTENANCE FACTOR: 1.25

TRANSMISSION TYPE: fixed ratio
MOTOR —
RATED POWER: 48.9 KW
CONTROLLER: 54.3 KW

TYPE: AC

DRIVING —
ANNUAL ELEC USE: 4480.493 KW-H

AMOUNT: 16610.67 KM/YEAR

— OUTPUTS —

COST ITEMS-

	$	C/KM			
BASIC VEHICLE COST	7353.25	4.427			
MOTOR COST	929.10	0.559			
CONTROLLER COST	2443.50	1.471			
EV TRANSMISSION COST	252.50	0.152			
BATTERY LOW	8360.80	5.033	HIGH	10701.82	6.443
INITIAL COST LOW	19339.14	11.643	HIGH	21680.16	13.052
DOWNPAYMENT LOW	3867.83	2.329	HIGH	4336.03	2.610
REPLACEM'T BATTS LOW	0.00	0.000	HIGH	0.00	0.000
REPAIRS & MAINTENANCE	3184.32	1.917			
REPLACEMENT TIRES	549.18	0.331			
INSURANCE	3479.00	2.094			
GARAGING,PARK, TOLL	782.50	0.471			
TITLE, REG, LIC, LOW,	1166.96	0.703	HIGH	1284.01	0.773
ELECTRICITY	2240.25	1.349			
PRIN & INT LOW	15471.31	9.314	HIGH	17344.13	10.442
OPERATING COST LOW	26873.51	16.178	HIGH	28863.38	17.376
VEHICLE SALVAGE VALUE LOW	423.26	0.255	HIGH	423.26	0.255
BATTERY SALVAGE LOW	125.46	0.076	HIGH	125.46	0.076
TOTAL LIFE CYCLE COST LOW	30192.62	18.177	HIGH	32650.69	19.656

ELECTRIC AND HYBRID VEHICLE COST MODEL

50-mi PB/ACID HYBRID 08-29-1984

--INPUTS--

GENERAL --		YEAR:	1982
VEHICLE SIZE:	5-PASS	REAL INTEREST RATE:	10 %
CURB WEIGHT:	1747 KG	VEHICLE SALVAGE VALUE:	10 %
VEHICLE WEIGHT , WT:	1883		
LIFE:	166106.7 KM	ACCESSORY COST:	$ 200
BATTERY --		NAME:	PBAC/AD3.3
BATTERY WEIGHT:	410 KG	BATTERY CYCLE LIFE:	750
ELECTRICITY COST:	.05 $/KW-H	MAXIMUM SHELF LIFE:	10 YEARS
AVERAGE DAILY DEPTH OF DISCHARGE:	.3336073		
		DEPTH OF A DEEP DISCHARGE:	.8
MAINTENANCE FACTOR:	1		
ENGINE --		FUEL COST:	.373 $/L
TANK CAPACITY:	40 L	FUEL TYPE:	METHANOL
ICE TRANSMISSION TYPE:	CVT	POWER:	52.7 KW
MOTOR --			
RATED POWER:	47.5 KW	TYPE:	AC
CONTROLLER:	52.7 KW		
EV TRANSMISSION TYPE:	fixed ratio		
DRIVING --		AMOUNT:	16610.67 KM/YEAR
ICE FRACTIONAL RANGE:	22.15058 %	EV FRACTIONAL RANGE:	74.3363 %
ANNUAL FUEL USE:	486.0288 L	ANNUAL ELEC USE:	2635.126 KW-H

-- OUTPUTS --

COST ITEMS-

		$	C/KM		$	C/KM
BASIC VEHICLE COST		7267.10	4.375			
ENGINE COST		1331.99	0.802			
ICE TRANSMISSION COST		588.66	0.354			
MOTOR COST		902.50	0.543			
CONTROLLER COST		2371.50	1.428			
EV TRANSMISSION COST		245.06	0.148			
BATTERY	LOW	2164.30	1.303	HIGH	2748.66	1.655
INITIAL COST	LOW	14871.10	8.953	HIGH	15455.46	9.305
DOWNPAYMENT	LOW	2974.22	1.791	HIGH	3091.09	1.861
REPLACEM'T BATTS	LOW	4328.60	2.606	HIGH	5497.33	3.310
REPAIRS & MAINTENANCE		4289.90	2.583			
REPLACEMENT TIRES		541.03	0.326			
INSURANCE		3479.00	2.094			
GARAGING,PARK, TOLL		782.50	0.471			
TITLE, REG, LIC,	LOW.	943.56	0.568	HIGH	972.77	0.586
FUEL-OIL		1867.27	1.124			
ELECTRICITY		1317.56	0.793			
PRIN & INT	LOW	11896.88	7.162	HIGH	12364.37	7.444
OPERATING COST	LOW	29446.31	17.727	HIGH	29943.02	18.026
VEHICLE SALVAGE VALUE	LOW	2590.48	1.560	HIGH	3157.63	1.901
BATTERY SALVAGE	LOW	51.73	0.031	HIGH	51.73	0.031
TOTAL LIFE CYCLE COST	LOW	29778.33	17.927	HIGH	29824.75	17.955

GLOSSARY

ABBREVIATIONS AND ACRONYMS

ADOD	average daily depth of discharge
AELC	annual electricity use in kWh
AFUS	annual fuel use in liters
APINT	annual principal and interest payment (low)
APINTH	annual principal and interest payment (high)
AUP	mark-up OEM to sale price
BATT	battery name
BI	inflation factor
BLIF	battery shelf life
BVC	basic vehicle cost
BVCPKG	basic vehicle cost per kg
CACC	accessories cost $
CCON	controller cost
CEL	total cost of electricity
CFU	total cost of fuel and oil
CI	ratio of inflation to discount factor
CKW	power of controller
CMOT	motor cost
CONWT	controller weight
COSTRAN	cost of EV transmission $
CURBWT	vehicle curb weight kg
CWBT	battery cost $ (low)
CWBTH	battery cost $ (high)

CWRB	cost of replacement batteries (low) $
CWRBH	cost of replacement batteries (high) $
CYCB	battery cycle life in cycles
DDCG	depth of a deep discharge
DI	discount factor
DNBAT	difference between integer value of number of batteries and number of batteries
DPMH	downpayment (high)
DPML	downpayment (low)
DRBAT	difference between integer value of number of replacement batteries and number of replacement batteries
ECOSTRAIN	cost of EV transmission
ENGC	cost of engine $
ENGWT	engine weight
EOLY	EV fractional use of vehicle
EPOW	engine power
ETKW	EV transmission power
ETRAN	EV transmission type
ETRAN$	EV transmission type
ETRANWT	EV transmission weight
FI	inflation factor
FTYP	fuel type
FYEAR	number of years to finance over
GCOSTRAN	ICE transmission cost
GTRAN	ICE transmission type
GTRAN$	ICE transmission type
GTRANWT	ICE transmission weight

IDOL	1982
INBAT	integer value of the number of batteries
INIT	Initial cost (low $)
INITH	initial cost (high $)
INSR	cost of insurance $
IRBAT	integer value of number of replacement batteries
KMYR	annual travel in km per year
KWHR	kilowatt hour
LI	inflation factor
MCPKWH	battery material cost per kWh
ME	maintenance constant
MFAC	maintenance factor
MICE	maintenance constant
MKW	motor power
MOTWT	motor weight
MTYP$	Motor type
NBAT	number of batteries
NTRAN	number of transmissions
OPER	operating cost (low $)
OPERH	operating cost (high $)
PANDPL	passenger and payload
PAPINT	present value of principal and interest
PELEC	price of electricity
PFUEL	price of fuel
PTE	parking and toll
RBAT	number of replacement batteries

RBATYR	year of first replacement batteries
RDISR	real discount rate
RICE	fraction of ICE mileage
RINTR	real interest rate
RPM	repair and maintenance cost
RTIR	cost of replacement tires
SI	inflation factor
SLBV	salvage value of vehicle
SVB	salvage value of battery
SVB1	battery material salvage value (low)
SVB2	battery material salvage value (high)
SVV	salvage value of vehicle (low)
SVVH	salvage value of vehicle (high)
TEMP1	temporary addition to a sum
TEMP2	temporary addition to a sum
TEMP3	temporary addition to a sum
TEMP4	temporary addition to a sum
TEMP5	temporary addition to a sum
TEMP7	temporary addition to a sum
TEMP8	temporary addition to a sum
TEMP9	temporary addition to a sum
TEMP10	temporary addition to a sum
TI	inflation factor
TKM	total travel during life of vehicle
TRAWT	EV transmission weight
TRBATYR	year of second battery replacement
TRLE	cost of title and registration (low)

TRLEH	cost of title and registration (high)
TTL	total life-cycle cost (low)
TTLH	total life-cycle cost (high)
VGAS	tank volume in liters
VTYP	vehicle type (hybrid, electric, ICE)
WB	weight of battery
WBV	weight of basic vehicle
WT	test weight of vehicle
YEAR	life of vehicle in years
ZI	inflation factor

APPENDIX N

BATTERY DISCHARGE MODELS
BASED ON ASSESSMENT OF
AV BATTERY REVIEW BOARD

Battery model coefficient generator:

PB/ACID/1.0

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	47.99	4.799	2.30259	1.56841
20	45.06	2.253	2.99573	.812263
30	41.99	1.39967	3.4012	.336234
40	38.75	.96875	3.68888	-.0317485
50	35.29	.7058	3.91202	-.348423
60	31.48	.524667	4.09435	-.644992
70	27.11	.387286	4.2485	-.948593
80	21.38	.26725	4.38203	-1.31957

RESULTS -----

ln(Pd) = 3.66561 + -.705735 *ln(tau) + -.110161 *[ln(tau)]^2

CH1 = 3.66561
CH2 = -.705735
CH3 = -.110161

Sum of the squares of the residuals = 2.26633E-03
Standard error estimate = .0194351
Coefficient of determination = .999346

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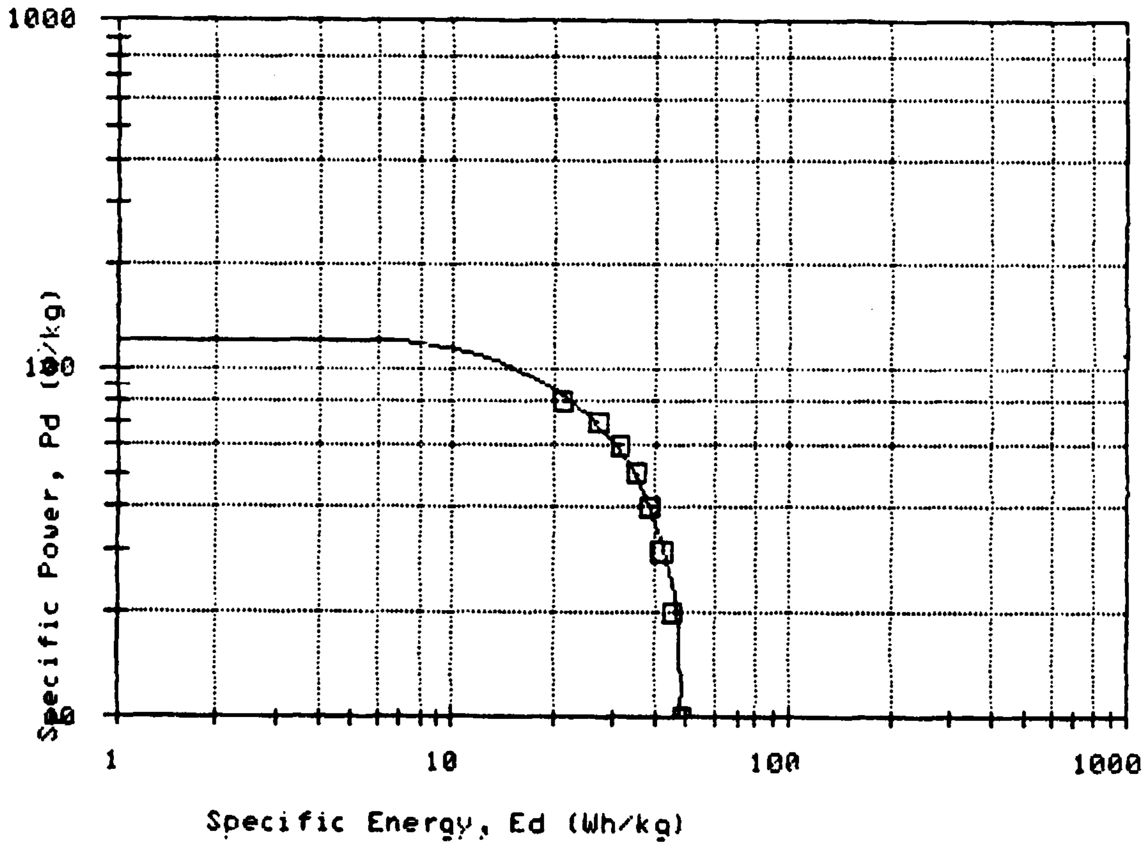
ELVEC battery CH coefficient curve plot.....

For battery: PB/ACID/1.0

CH-1 = 3.66561 Pdmax = 120
CH-2 = -.705735
CH-3 = -.110161



Battery model coefficient generator:

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PB/ACID2.1

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	45.74	4.574	2.30259	1.52039
20	43.01	2.1505	2.99573	.7657
30	40.2	1.34	3.4012	.29267
40	37.29	.93225	3.68888	-.070154
50	34.25	.685	3.91202	-.378337
60	31.03	.517167	4.09435	-.65939
70	27.6	.394286	4.2485	-.930679
80	23.8	.2975	4.38203	-1.21234
90	19.32	.214667	4.49981	-1.53867
100	12.36	.1236	4.60517	-2.0907
135	1.13	8.37037E-03	4.90528	-4.78306

RESULTS -----

ln(Pd) = 3.62626 + -.717755 *ln(tau) + -.094989 *[ln(tau)]^2

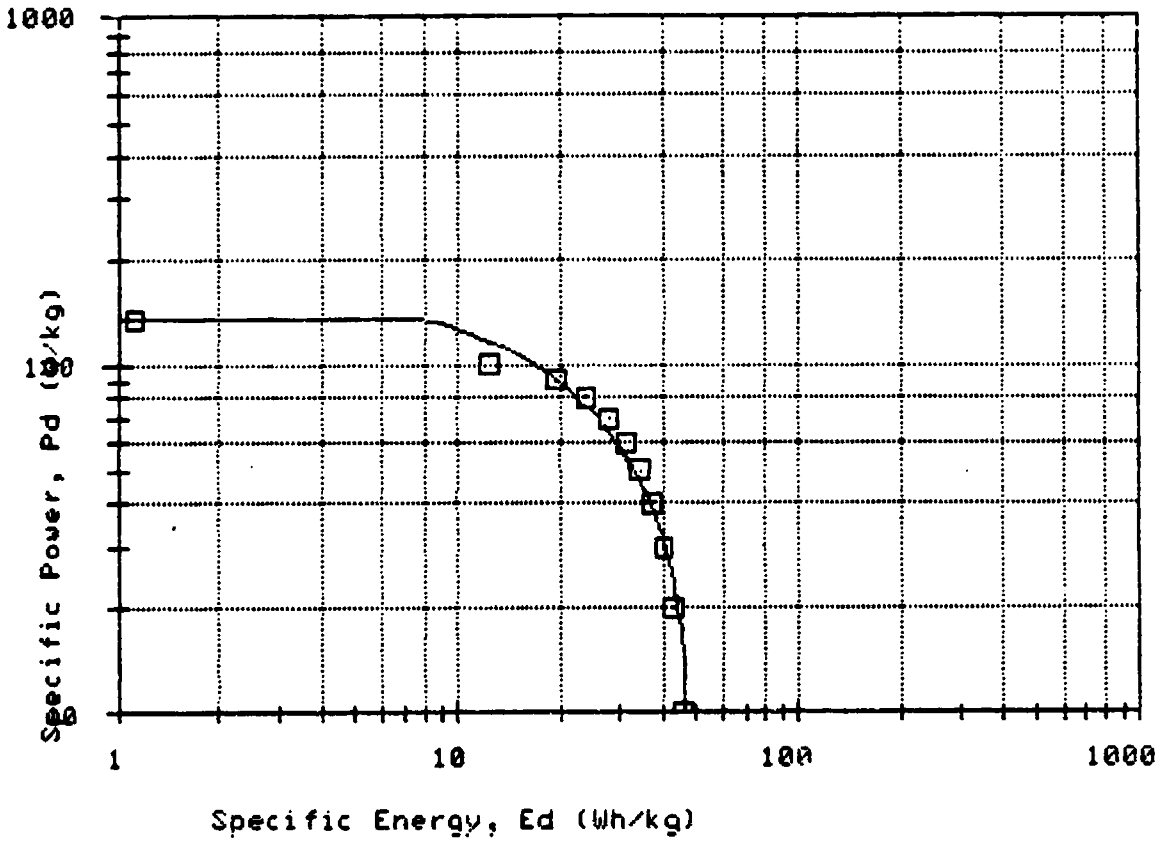
CH1 = 3.62626
CH2 = -.717755
CH3 = -.094989

Sum of the squares of the residuals = .0167992
Standard error estimate = .043204
Coefficient of determination = .997163

ELVEC battery CH coefficient curve plot.....

For battery: PB/ACID2.1

CH-1 = 3.62626 Pdmax = 135
CH-2 = -.717755
CH-3 = -.094989



Battery model coefficient generator:

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PB/ACID/2.4

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	42.59	4.259	2.30259	1.44903
20	40.61	2.0305	2.99573	.708282
30	38.56	1.28533	3.4012	.251018
40	36.44	.911	3.68888	-.0932123
50	34.22	.6844	3.91202	-.379213
60	31.87	.531167	4.09435	-.632679
70	29.37	.419572	4.2485	-.868522
80	26.63	.332875	4.38203	-1.09999
90	23.52	.261333	4.49981	-1.34196
100	19.65	.1965	4.60517	-1.62709

RESULTS -----

ln(Pd) = 3.62408 + -.782033 *ln(tau) + -.0989376 *[ln(tau)]^2

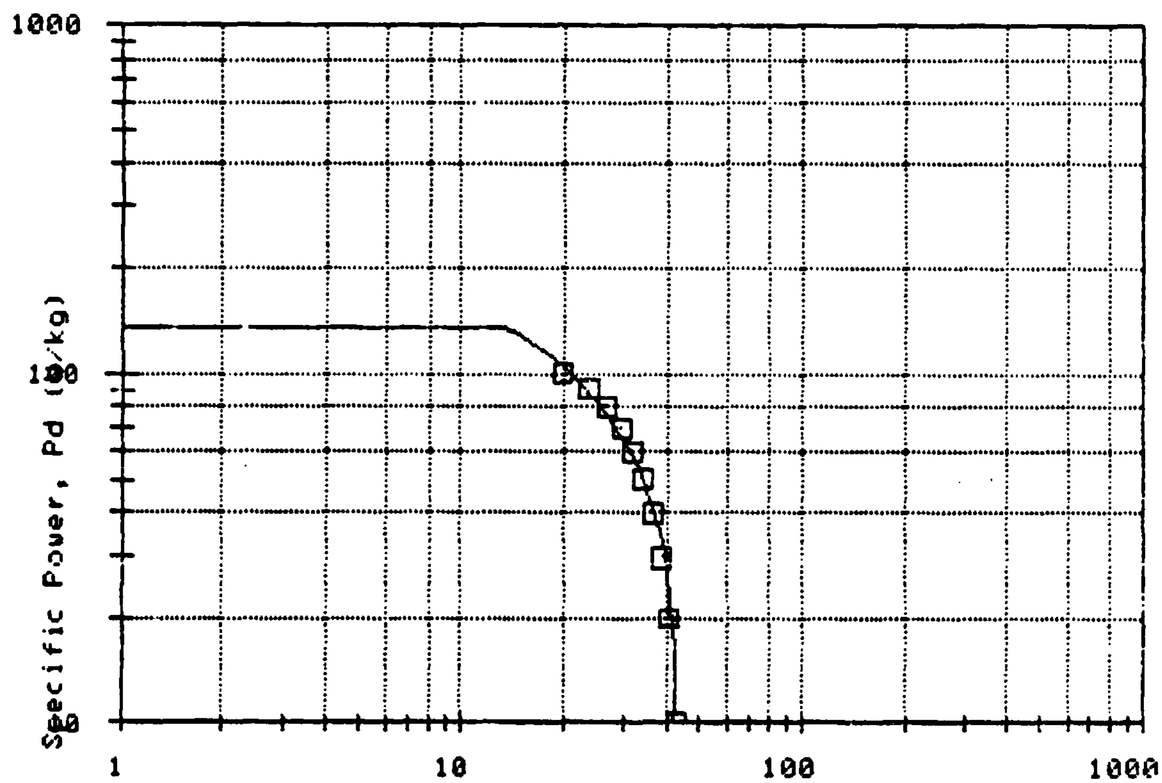
CH1 = 3.62408
CH2 = -.782033
CH3 = -.0989376

Sum of the squares of the residuals = 3.30163E-03
Standard error estimate = .0203151
Coefficient of determination = .999317

ELVEC battery CH coefficient curve plot.....

For battery: PB/ACID/2.4

CH-1 = 3.62408 Pdmax = 135
CH-2 = -.782033
CH-3 = -.0989376



Battery model coefficient generator:

PB/ACID/3.3

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	39.43	3.943	2.30259	1.37194
20	37.86	1.893	2.99573	.638163
30	36.25	1.20833	3.4012	.189242
40	34.57	.86425	3.68888	-.145893
50	32.83	.6566	3.91202	-.42068
60	31	.516667	4.09435	-.660358
70	29.06	.415143	4.2485	-.879133
80	26.97	.337125	4.38203	-1.0873
90	24.66	.274	4.49981	-1.29463
100	22	.22	4.60517	-1.51413

RESULTS -----

ln(Pd) = 3.57472 + -.822528 *ln(tau) + -.0838422 *[ln(tau)]^2

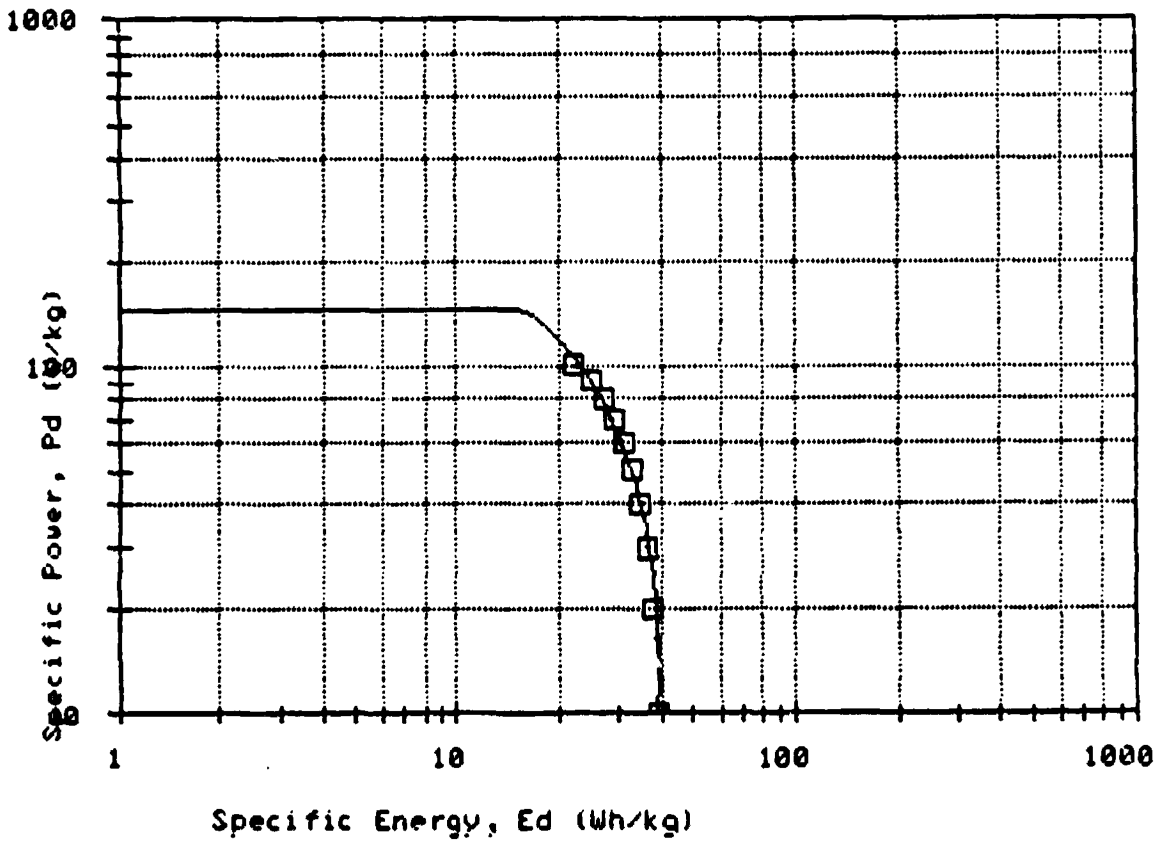
CH1 = 3.57472
CH2 = -.822528
CH3 = -.0838422

Sum of the squares of the residuals = 1.94499E-03
Standard error estimate = .0155924
Coefficient of determination = .999598

ELVEC battery CH coefficient curve plot.....

For battery: PB/ACID/3.3

CH-1 = 3.57472　　Pdmax = 145
CH-2 = -.822528
CH-3 = -.0838422



Battery model coefficient generator:

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BIP PB/ACID/10.0

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	50.96	5.096	2.30259	1.62846
20	49.93	2.4965	2.99573	.91489
30	48.88	1.62933	3.4012	.488171
40	47.82	1.1955	3.68888	.178565
50	46.74	.9348	3.91202	-.0674225
60	45.64	.760667	4.09435	-.27356
70	44.52	.636	4.2485	-.452557
80	43.38	.54225	4.38203	-.612028
90	42.22	.469111	4.49981	-.756916
100	41.02	.4102	4.60517	-.89111

RESULTS -----

ln(Pd) = 3.84895 + -.890158 *ln(tau) + -.0380122 *[ln(tau)]^2

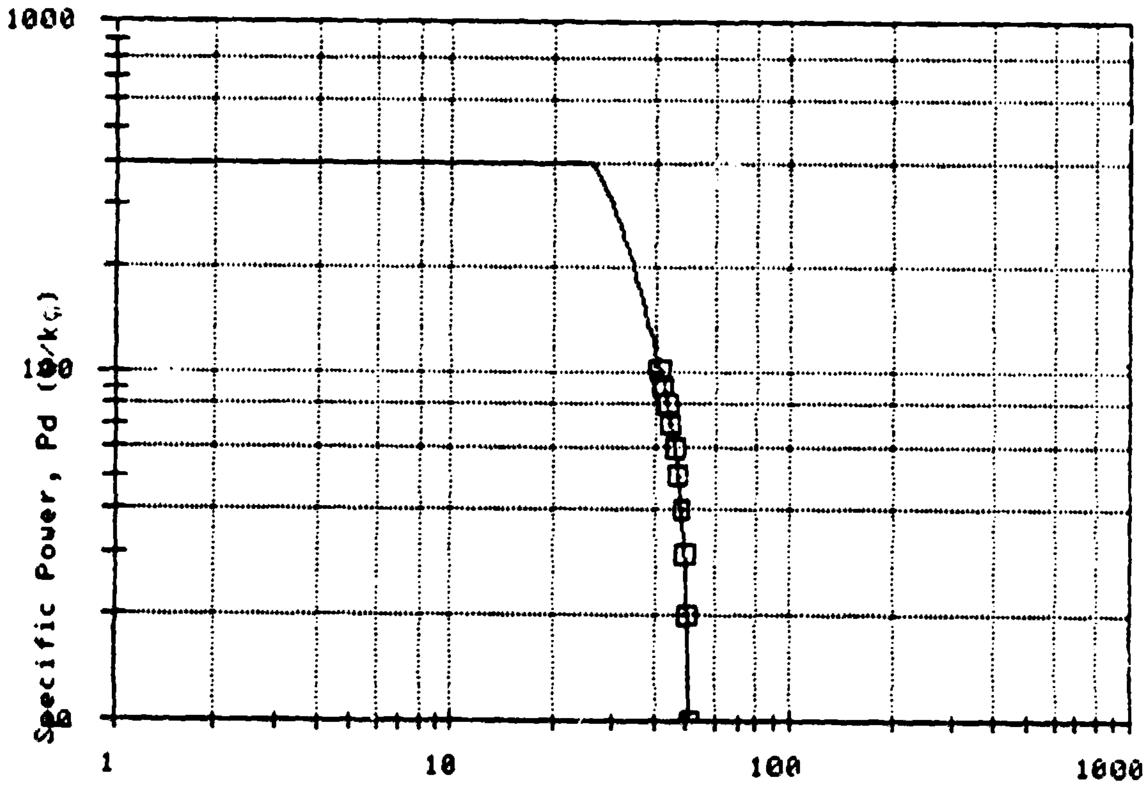
CH1 = 3.84895
CH2 = -.890158
CH3 = -.0380122

Sum of the squares of the residuals = 1.89471E-04
Standard error estimate = 4.86661E-03
Coefficient of determination = .999961

ELVEC battery CH coefficient curve plot.....

For battery: BIP PB/ACID/10.0

CH-1 = 3.84895 Pdmax = 400
CH-2 = -.890158
CH-3 = -.0380122



Battery model coefficient generator:

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NI/FE/1.0

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	57.37	5.737	2.30259	1.74694
20	55.67	2.7835	2.99573	1.02371
30	53.35	1.77833	3.4012	.575677
40	50.65	1.26625	3.68888	.23606
50	47.47	.9494	3.91202	-.0519249
60	43.53	.7255	4.09435	-.320894
70	37.78	.539714	4.2485	-.616716

RESULTS -----

ln(Pd) = 3.85854 + -.723694 *ln(tau) + -.0985473 *[ln(tau)]^2

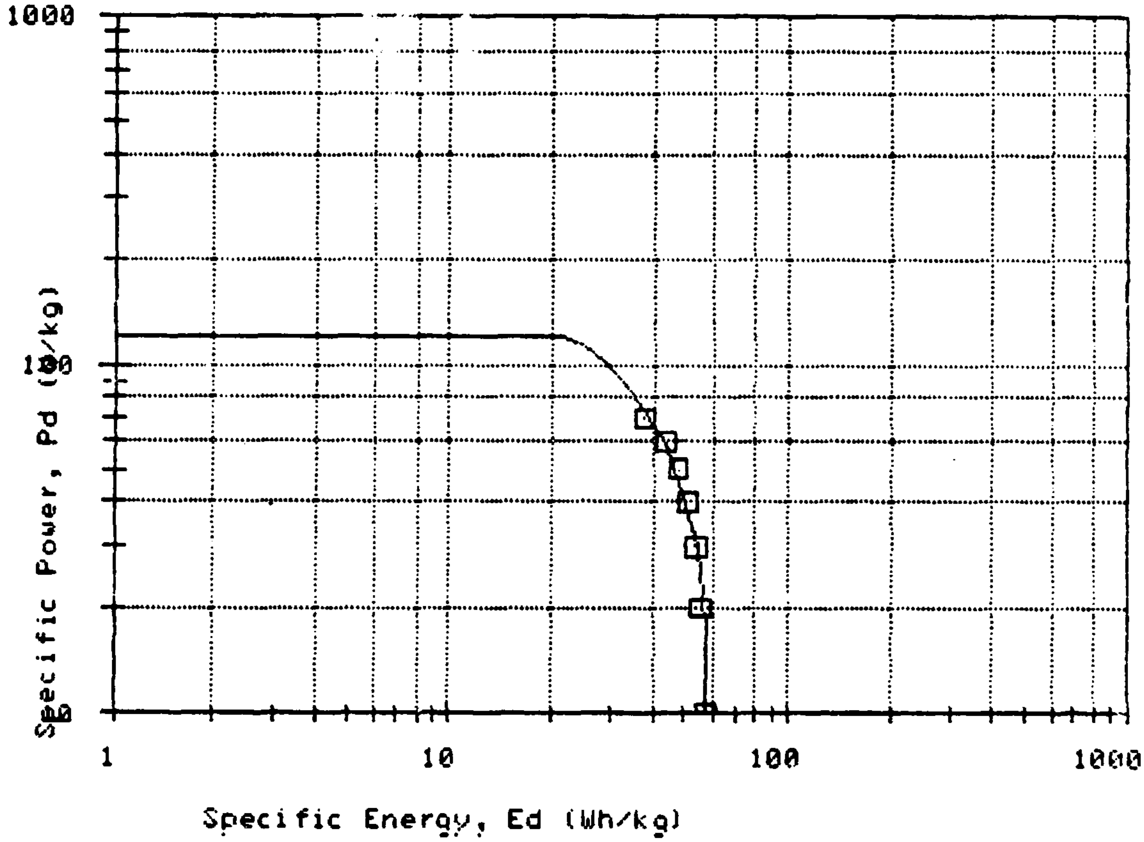
CH1 = 3.85854
CH2 = -.723694
CH3 = -.0985473

Sum of the squares of the residuals = 1.34634E-03
Standard error estimate = .0164094
Coefficient of determination = .999522

ELVEC battery CH coefficient curve plot.....

For battery: Ni/FE/1.0

CH-1 = 3.95854 Pdmax = 120
CH-2 = -.723694
CH-3 = -.0985473



Battery model coefficient generator:

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NI/FE/2.1

DATA -----

Pd	Fd	tau	ln(Pd)	ln(tau)
10	55.28	5.528	2.30259	1.70983
20	54.35	2.7175	2.99573	.999712
30	52.97	1.76567	3.4012	.568529
40	51.4	1.285	3.68888	.250759
50	49.67	.9934	3.91202	-6.62171E-03
60	47.76	.796	4.09435	-.228156
70	45.61	.651572	4.2485	-.428368
80	43.15	.539375	4.38203	-.617344
90	40.16	.446222	4.49981	-.806938
100	36.05	.3605	4.60517	-1.02026

RESULTS -----

ln(Pd) = 3.9014 + -.802984 *ln(tau) + -.0824347 *[ln(tau)]^2

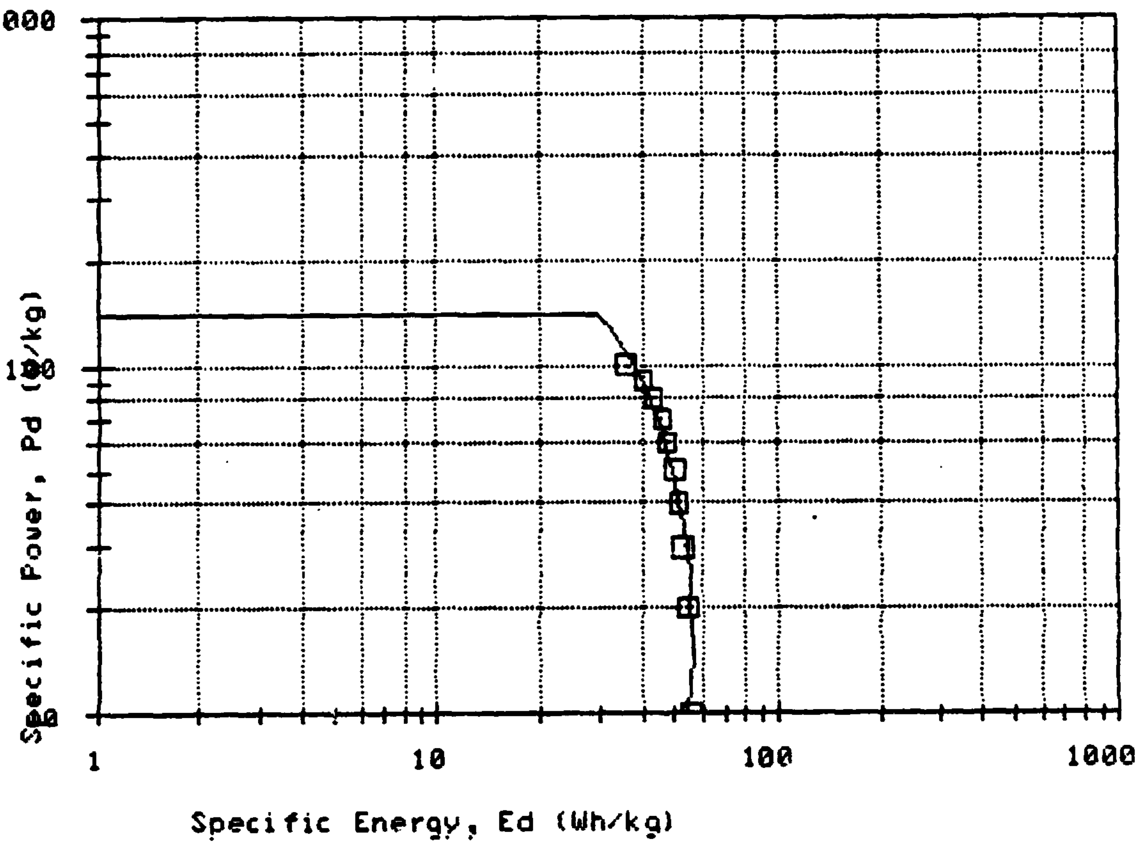
CH1 = 3.9014
CH2 = -.802984
CH3 = -.0824347

Sum of the squares of the residuals = 2.69918E-03
Standard error estimate = .0183684
Coefficient of determination = .999442

ELVEC battery CH coefficient curve plot.....

For battery: NI/FE/2.1

CH-1 = 3.9014   Pdmax = 141
CH-2 = -.802984
CH-3 = -.0824347



Battery model coefficient generator:

NI/FE/2.4

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	53.4	5.34	2.30259	1.67523
20	52.5	2.625	2.99573	.965081
30	51.19	1.70633	3.4012	.534347
40	49.71	1.24275	3.68888	.217327
50	48.08	.9616	3.91202	-.0391565
60	46.31	.771833	4.09435	-.258986
70	44.36	.633714	4.2485	-.456157
80	42.15	.526875	4.38203	-.640792
90	39.58	.439778	4.49981	-.821486
100	36.35	.3635	4.60517	-1.01198

RESULTS -----

ln(Pd) = 3.87467 + -.820591 *ln(tau) + -.0747063 *[ln(tau)]^2

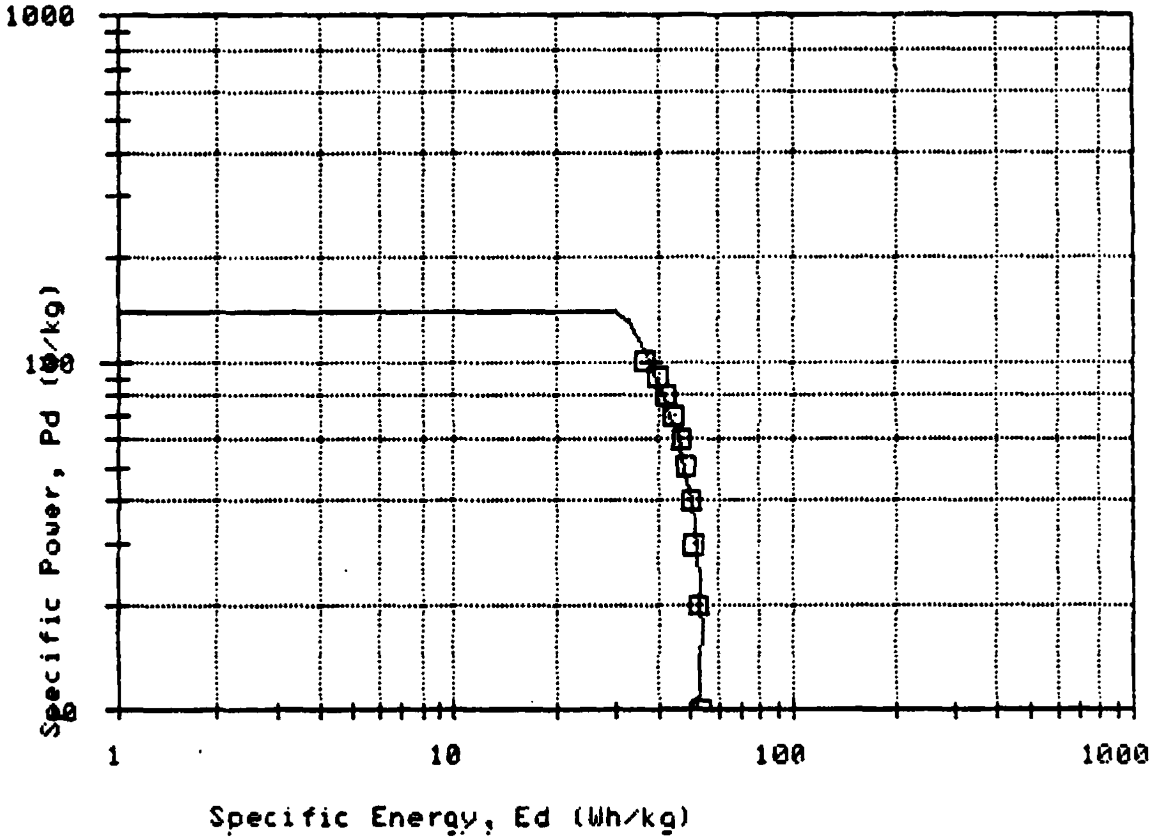
CH1 = 3.87467
CH2 = -.820591
CH3 = -.0747063

Sum of the squares of the residuals = 1.75763E-03
Standard error estimate = .0148224
Coefficient of determination = .999637

ELVEC battery CH coefficient curve plot.....

For battery: NI/FE/2.4

CH-1 = 3.87467 Pdmax = 141
CH-2 = -.820591
CH-3 = -.0747063



Battery model coefficient generator:

NI/FE/3.3

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DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	48.55	4.855	2.30259	1.58001
20	47.99	2.3995	2.99573	.875261
30	47.11	1.57033	3.4012	.451288
40	46.13	1.15325	3.68888	.142584
50	45.06	.9012	3.91202	-.104028
60	43.91	.731833	4.09435	-.312202
70	42.68	.609714	4.2485	-.494765
80	41.36	.517	4.38203	-.659712
90	39.91	.443445	4.49981	-.813183
100	38.32	.3832	4.60517	-.959198

RESULTS -----

ln(Pd) = 3.81662 + -.882478 *ln(tau) + -.0504292 *[ln(tau)]^2

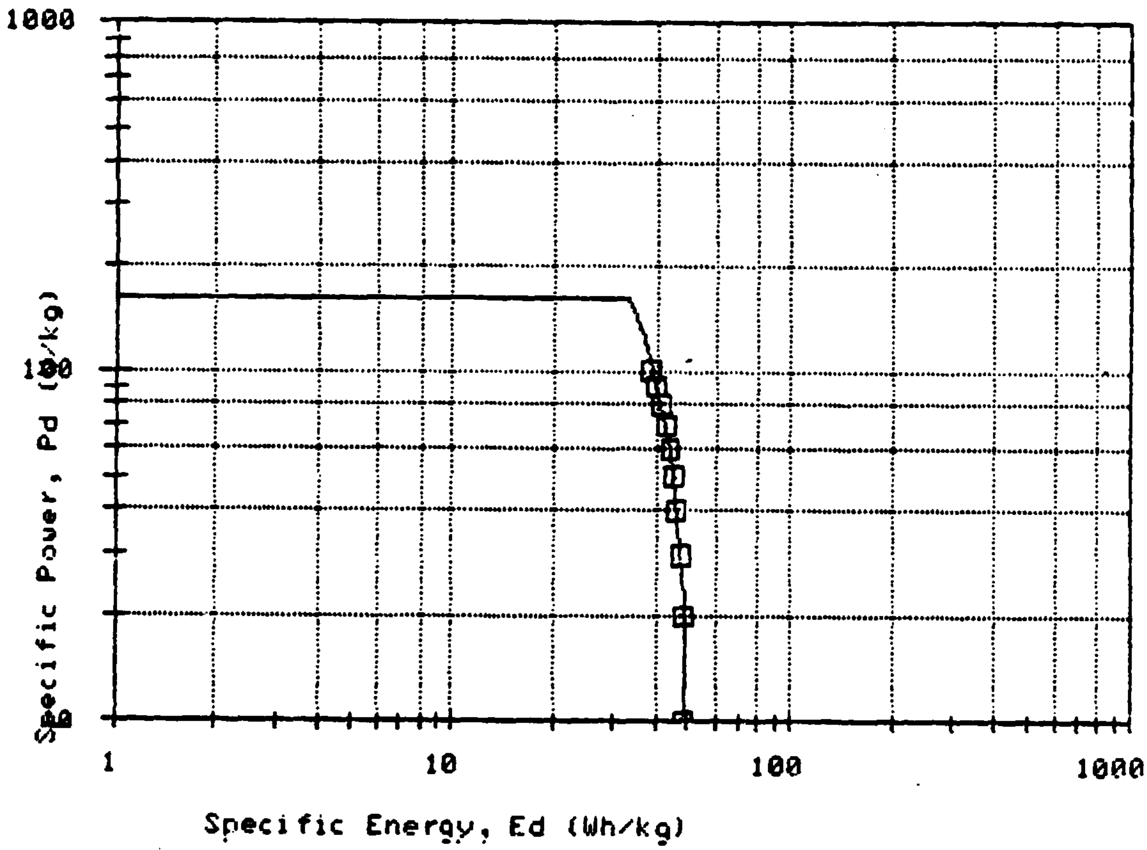
CH1 = 3.81662
CH2 = -.882478
CH3 = -.0504292

Sum of the squares of the residuals = 4.70245E-04
Standard error estimate = 7.66686E-03
Coefficient of determination = .999903

ELVEC battery CH coefficient curve plot.....

For battery: NI/FE/3.3

CH-1 = 3.81662 Pdmax = 160
CH-2 = -.882478
CH-3 = -.0504292



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Battery model coefficient generator:

NI/ZN2.0

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	60	6	2.30259	1.79176
20	60	3	2.99573	1.09861
60	58	.966667	4.09435	-.0339015
100	53	.53	4.60517	-.634878
150	40	.266667	5.01064	-1.32176

RESULTS -----

ln(Pd) = 4.06488 + -.844001 *ln(tau) + -.0847194 *[ln(tau)]^2

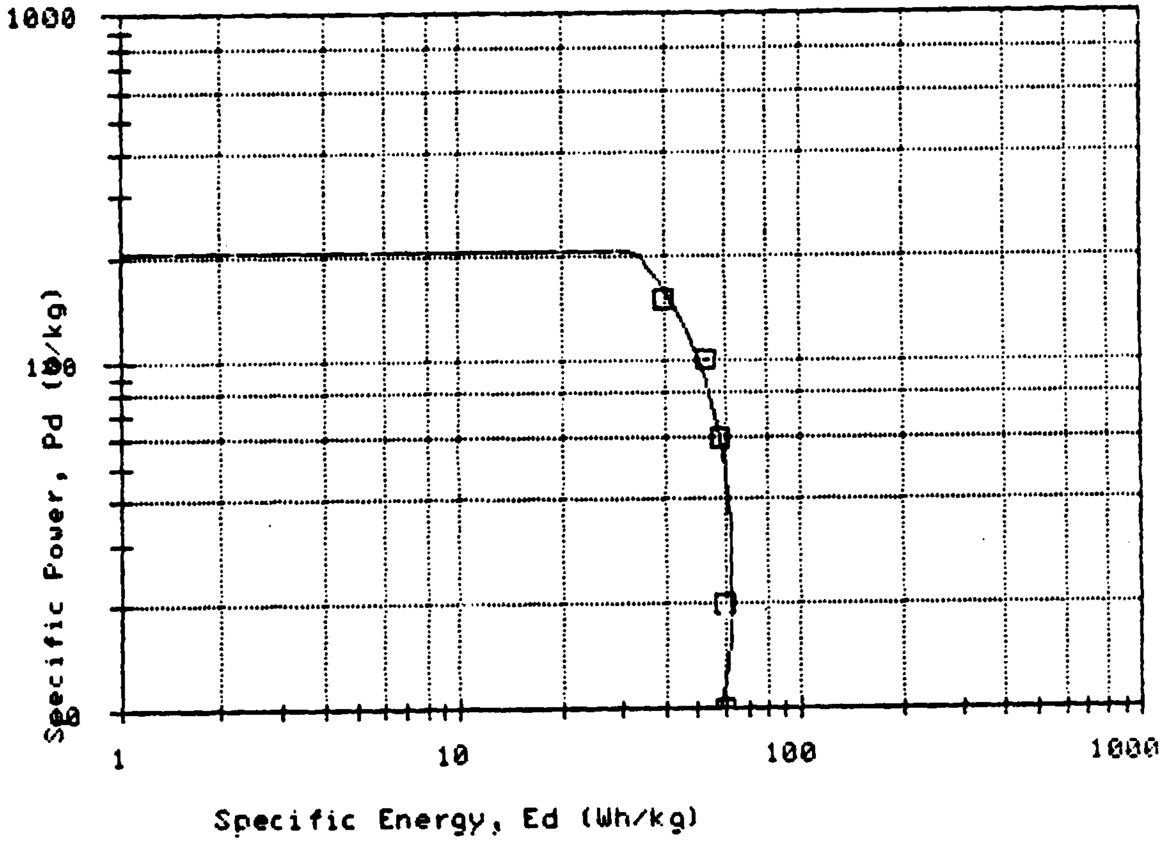
CH1 = 4.06488
CH2 = -.844001
CH3 = -.0847194

Sum of the squares of the residuals = 4.02063E-03
Standard error estimate = .0366089
Coefficient of determination = .99921

ELVEC battery CH coefficient curve plot.....

For battery: NI/ZN2.0

CH-1 = 4.06488 Pdmax = 204
CH-2 = -.844001
CH-3 = -.0847194



Battery model coefficient generator:

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ZN/BR/1.0

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	65.99	6.599	2.30259	1.88692
20	66.88	3.344	2.99573	1.20717
30	65.04	2.168	3.4012	.773805
40	62.2	1.555	3.68888	.441476
50	58.66	1.1732	3.91202	.159735
60	54.31	.905167	4.09435	-.0996361
70	48.58	.694	4.2485	-.365283
80	35	.4375	4.38203	-.826679

RESULTS -----

ln(Pd) = 4.00357 + -.627864 *ln(tau) + -.151306 *[ln(tau)]^2

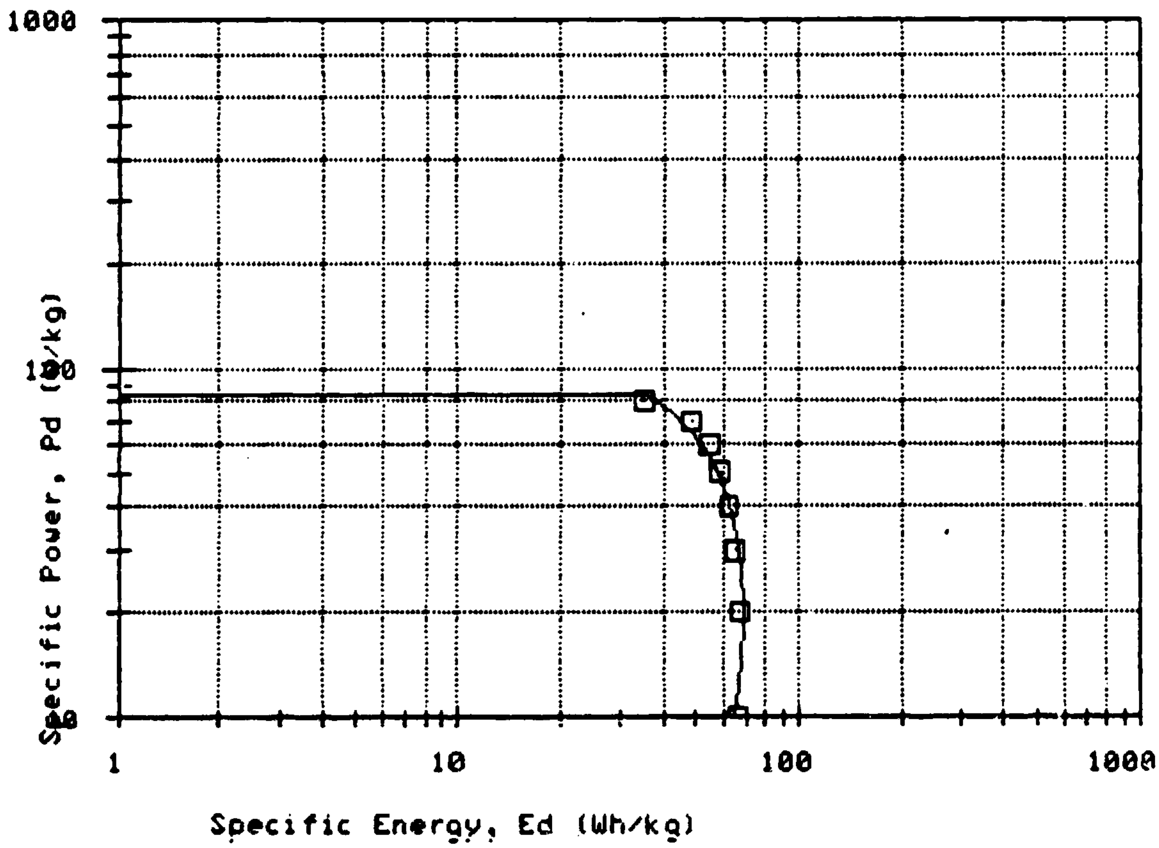
CH1 = 4.00357
CH2 = -.627864
CH3 = -.151306

Sum of the squares of the residuals = 5.80993E-03
Standard error estimate = .0311179
Coefficient of determination = .998322

ELVEC battery CH coefficient curve plot.....

For battery: ZN/BR/1.0

CH-1 = 4.00357 Pdmax = 83
CH-2 = -.627864
CH-3 = -.151306



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Battery model coefficient generator:

ZN/BE/2.1

DATA ------

Pd	Ed	tau	ln(Pd)	ln(tau)
10	47.87	4.787	2.30259	1.5659
20	48.47	2.4235	2.99573	.885213
30	47.47	1.58233	3.4012	.458901
40	45.97	1.14925	3.68888	.13911
50	44.21	.8842	3.91202	-.123072
60	42.25	.704167	4.09435	-.35074
70	40.08	.572571	4.2485	-.557618
80	37.68	.471	4.38203	-.752897
90	34.97	.388556	4.49981	-.945319
100	31.76	.3176	4.60517	-1.14696

RESULTS -----

ln(Pd) = 3.80889 + -.819456 *ln(tau) + -.0951689 *[ln(tau)]^2

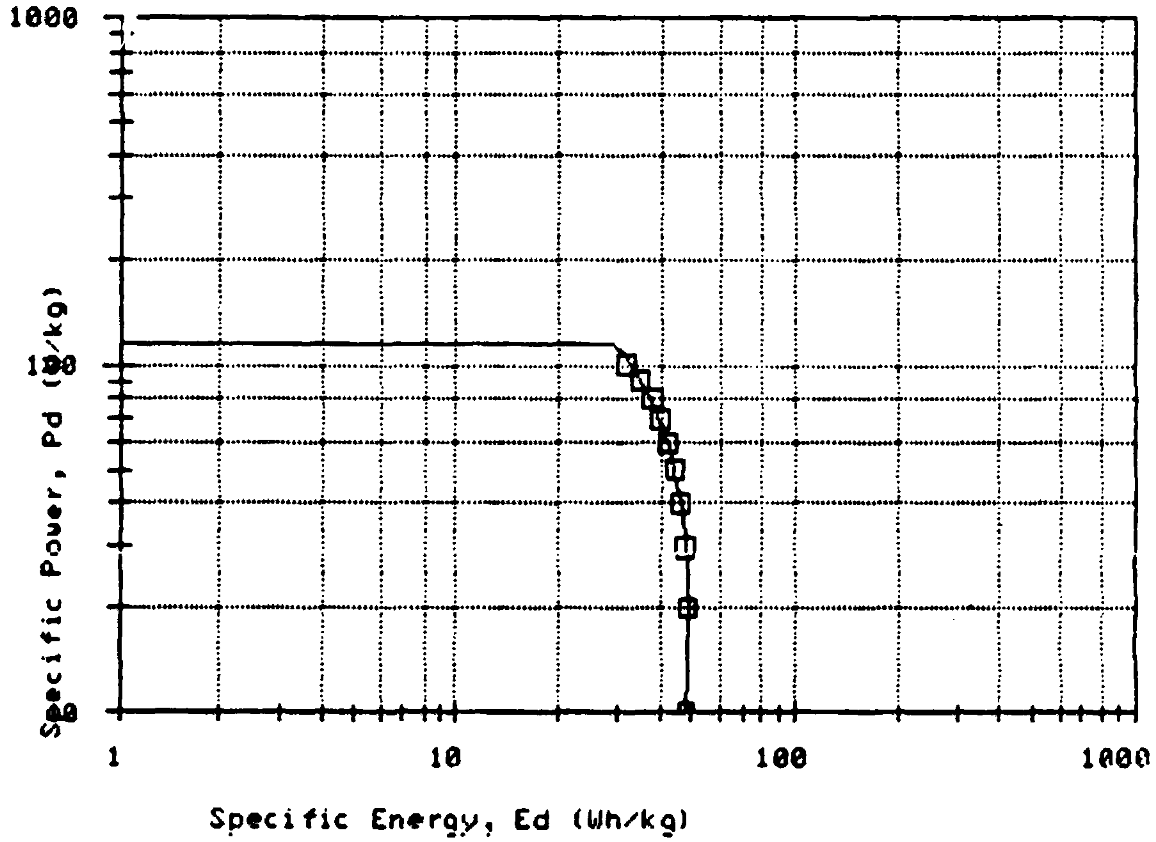
CH1 = 3.80889
CH2 = -.819456
CH3 = -.0951689

Sum of the squares of the residuals = 1.13292E-03
Standard error estimate = .0119002
Coefficient of determination = .999766

ELVEC battery CH coefficient curve plot.....

For battery: ZN/BE/2.1

CH-1 = 3.80889 Pdmax = 115
CH-2 = -.819456
CH-3 = -.0951689



Battery model coefficient generator:

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ZN/BR/2.4

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	48.75	4.875	2.30259	1.58412
20	49.54	2.477	2.99573	.907048
30	48.69	1.623	3.4012	.484276
40	47.35	1.18375	3.68888	.168687
50	45.76	.9152	3.91202	-.0886125
60	43.99	.733167	4.09435	-.310382
70	42.07	.601	4.2485	-.50916
80	39.97	.499625	4.38203	-.693897
90	37.66	.418445	4.49981	-.871211
100	35.08	.3508	4.60517	-1.04754

RESULTS -----

ln(Pd) = 3.83512 + -.837169 *ln(tau) + -.0851764 *[ln(tau)]^2

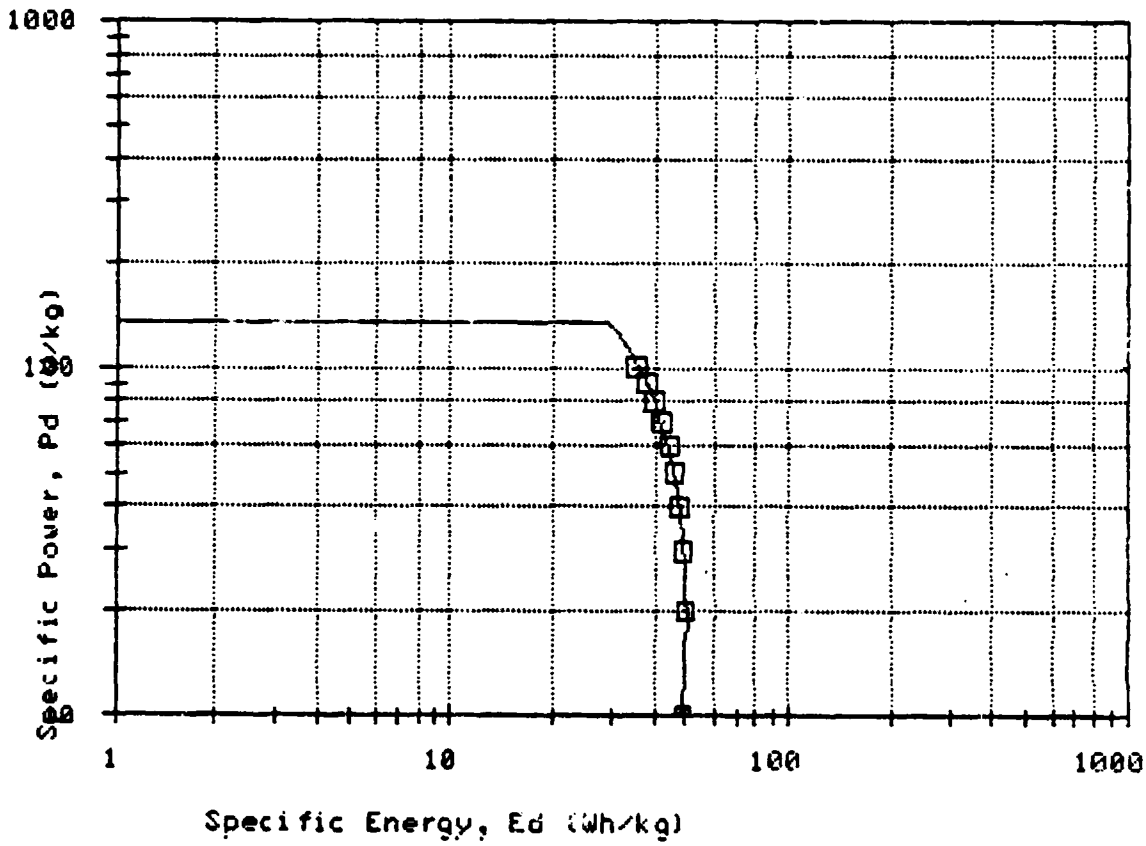
CH1 = 3.83512
CH2 = -.337169
CH3 = -.0851764

Sum of the squares of the residuals = 6.16919E-04
Standard error estimate = 8.78151E-03
Coefficient of determination = .999873

ELVEC battery CH coefficient curve plot.....

For battery: ZN/BR/2.4

CH-1 = 3.83512 Pdmax = 135
CH-2 = -.837169
CH-3 = -.0851764



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Battery model coefficient generator:

ZN/BR/3.3

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	40	4	2.30259	1.38629
20	40.5	2.025	2.99573	.70557
30	39.73	1.32433	3.4012	.280909
40	38.59	.96475	3.68888	-.0358862
50	37.29	.7458	3.91202	-.293298
60	35.87	.597833	4.09435	-.514443
70	34.36	.490857	4.2485	-.711602
80	32.78	.40975	4.38203	-.892208
90	31.1	.345556	4.49981	-1.0626
100	29.33	.2933	4.60517	-1.22656

RESULTS -----

ln(Pd) = 3.65918 + -.874489 *ln(tau) + -.0779032 *[ln(tau)]^2

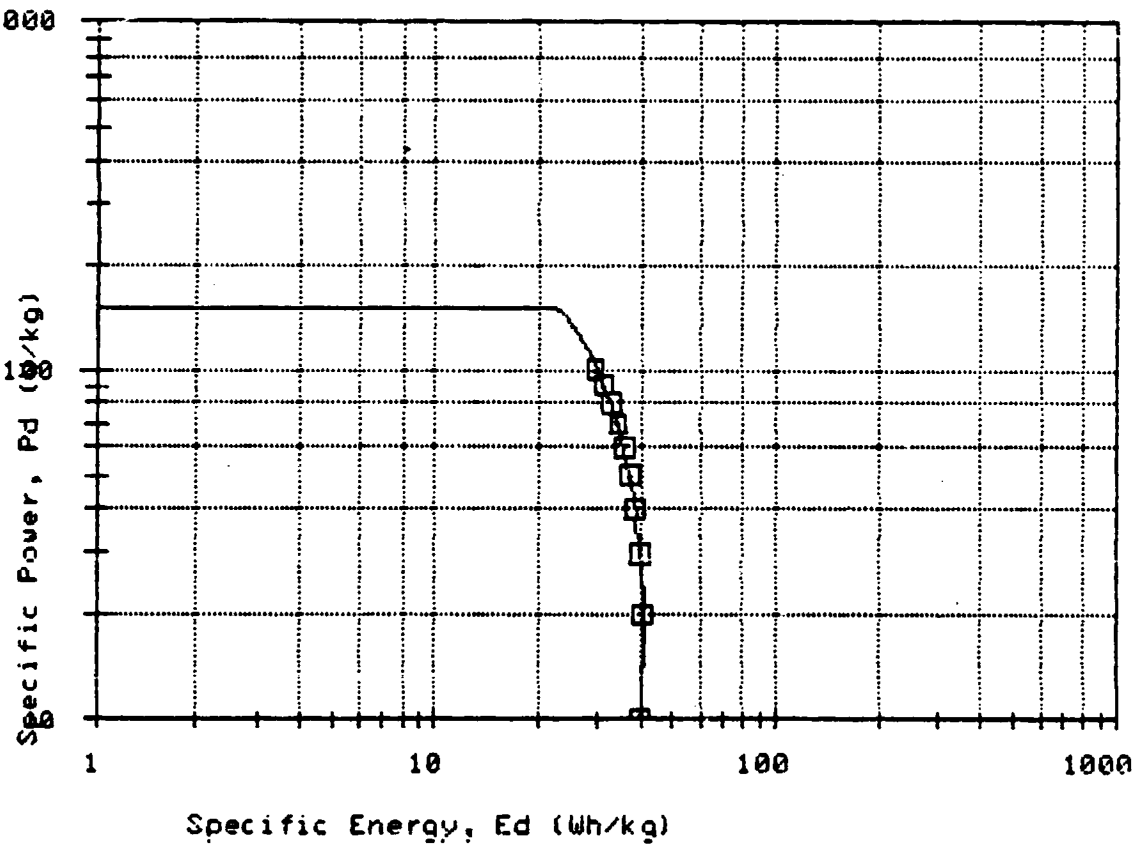
CH1 = 3.65918
CH2 = -.874489
CH3 = -.0779032

Sum of the squares of the residuals = 3.25496E-04
Standard error estimate = 6.37863E-03
Coefficient of determination = .999933

ELVEC battery CH coefficient curve plot.....

For battery: ZN/BR/3.3

CH-1 = 3.65918 Pdmax = 150
CH-2 = -.874489
CH-3 = -.0779032



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Battery model coefficient generator:

ZN/CL/1.0

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	86.63	8.663	2.30259	2.15906
20	88.94	4.447	2.99573	1.49223
30	87.59	2.91967	3.4012	1.07147
40	85.04	2.126	3.68888	.754242
50	81.76	1.6352	3.91202	.491765
60	77.83	1.29717	4.09435	.260182
70	73.09	1.04414	4.2485	.0431964
80	67.06	.83825	4.38203	-.176439
90	57.65	.640556	4.49981	-.44542

RESULTS -----

ln(Pd) = 4.2577 + -.658475 *ln(tau) + -.117385 *[ln(tau)]^2

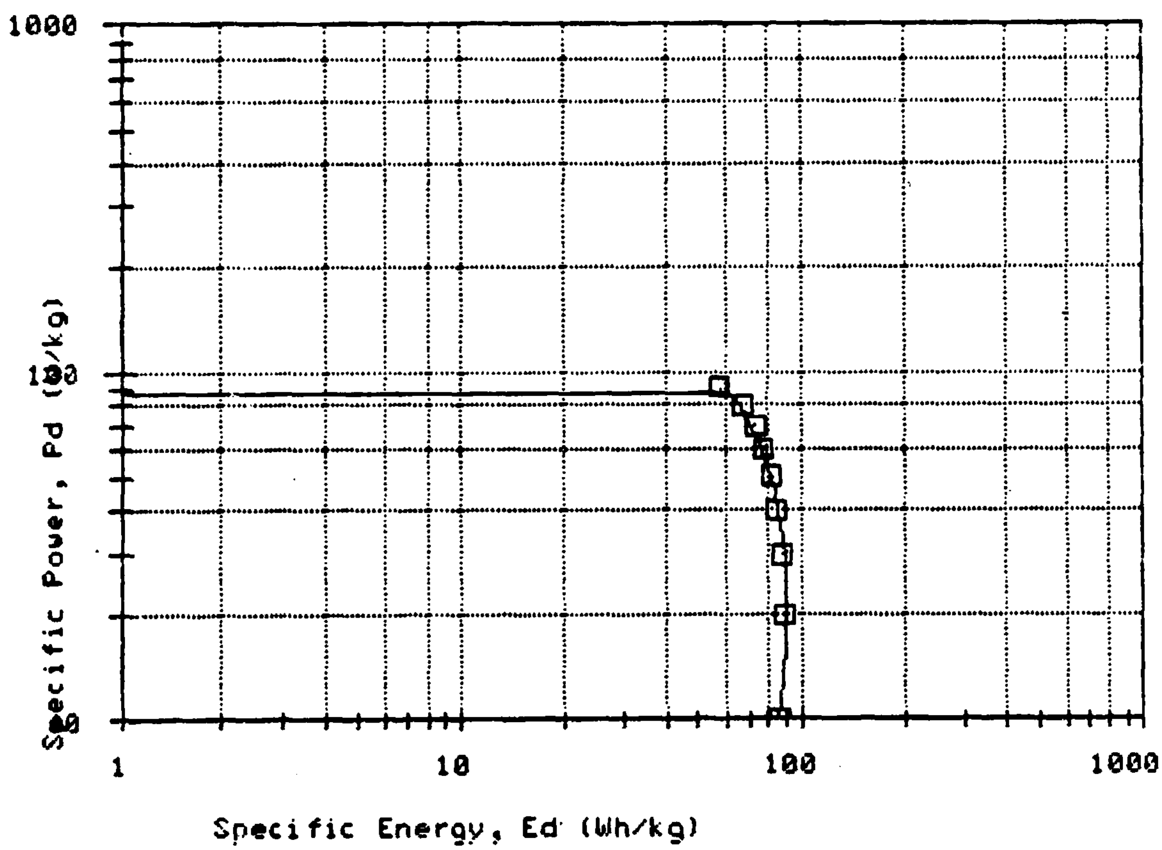
CH1 = 4.2577
CH2 = -.658475
CH3 = -.117385

Sum of the squares of the residuals = 2.3967E-03
Standard error estimate = .0185037
Coefficient of determination = .999421

ELVFC battery CH coefficient curve plot.....

For battery: ZN/CL/1.0

CH-1 = 4.2577 Pdmax = 86
CH-2 = -.658475
CH-3 = -.117385



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Battery model coefficient generator:

ZN/CL/2.1

DATA -----

Pd	Fd	tau	ln(Pd)	ln(tau)
10	53.15	5.315	2.30259	1.67053
20	53.95	2.6975	2.99573	.992326
30	53.09	1.76967	3.4012	.570791
40	51.71	1.29275	3.68888	.256772
50	50.06	1.0012	3.91202	1.19916E-03
60	48.19	.803167	4.09435	-.219193
70	46.1	.658572	4.2485	-.417682
80	43.76	.547	4.38203	-.603306
90	41.06	.456222	4.49981	-.784775
100	37.8	.378	4.60517	-.972861

RESULTS -----

ln(Pd) = 3.90924 + -.820198 *ln(tau) + -.0882068 *[ln(tau)]^2

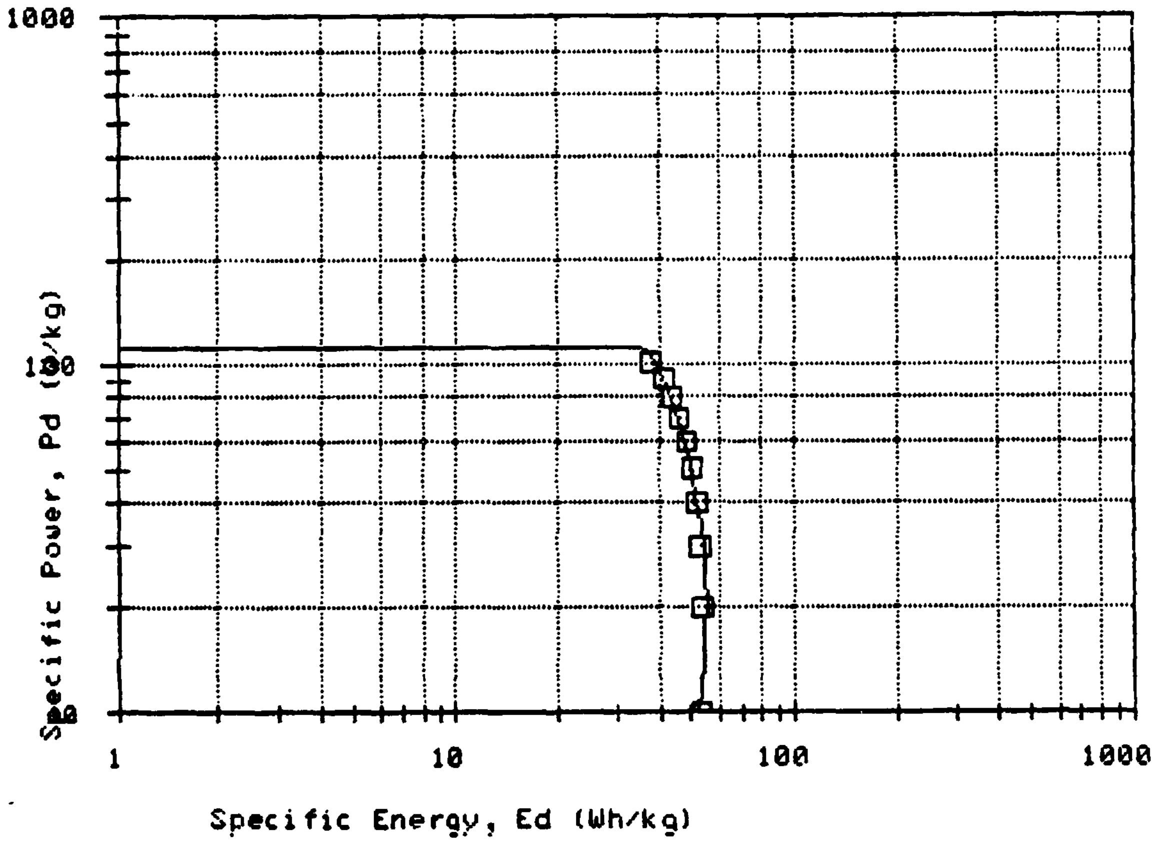
CH1 = 3.90924
CH2 = -.820198
CH3 = -.0882068

Sum of the squares of the residuals = 1.09263E-03
Standard error estimate = .0116867
Coefficient of determination = .999774

ELVEC battery CH coefficient curve plot.....

For battery: ZN/CL/2.1

CH-1 = 3.90924   Pdmax = 110
CH-2 = -.820198
CH-3 = -.0882068



Battery model coefficient generator:

ZN/CL/2.4

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	53.28	5.328	2.30259	1.67298
20	54.25	2.7125	2.99573	.997871
30	53.58	1.786	3.4012	.579979
40	52.42	1.3105	3.68888	.270409
50	51.01	1.0202	3.91202	.0199988
60	49.42	.823667	4.09435	-.193989
70	47.68	.681143	4.2485	-.383983
80	45.77	.572125	4.38203	-.558398
90	43.66	.485111	4.49981	-.723377
100	41.28	.4128	4.60517	-.884792

RESULTS -----

ln(Pd) = 3.9258 + -.848145 *ln(tau) + -.0752426 *[ln(tau)]^2

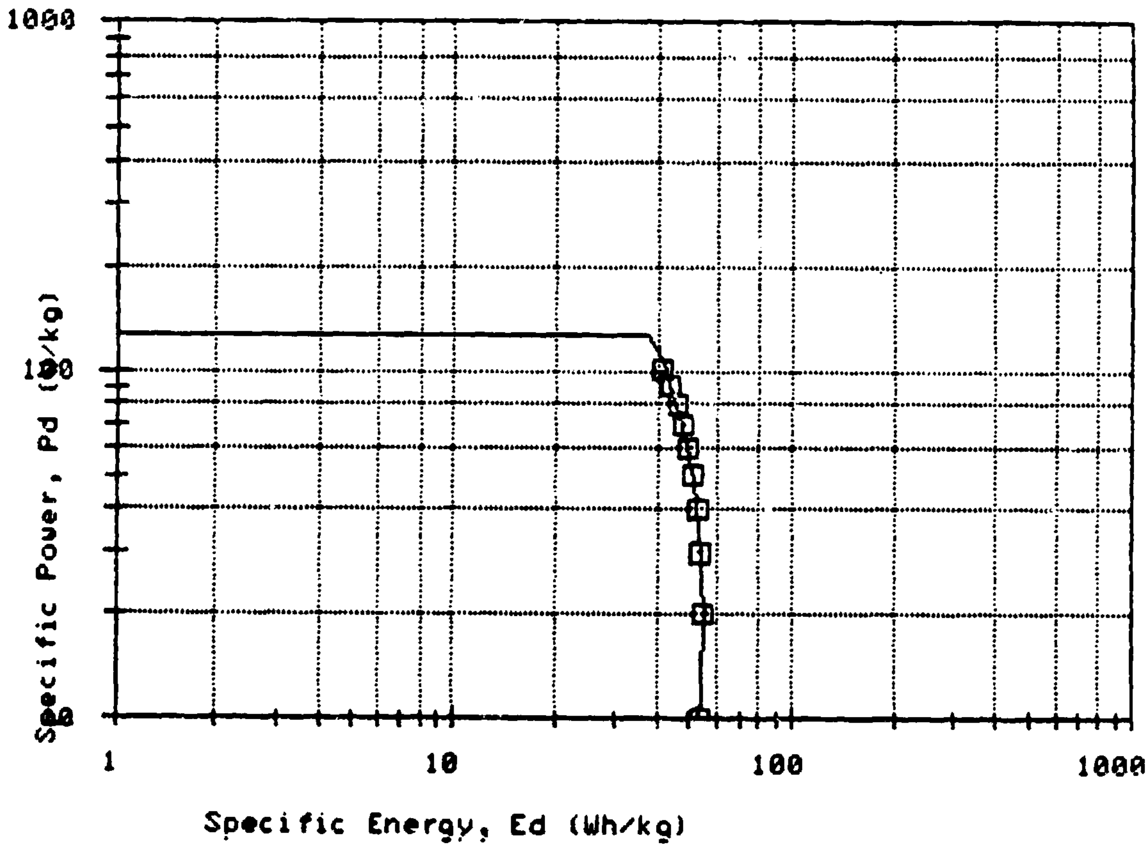
CH1 = 3.9258
CH2 = -.848145
CH3 = -.0752426

Sum of the squares of the residuals = 4.84082E-04
Standard error estimate = 7.77883E-03
Coefficient of determination = .9999

ELVEC battery CH coefficient curve plot.....

For battery: ZN/CL/2.4

CH-1 = 3.9258 Pdmax = 127
CH-2 = -.848145
CH-3 = -.0752426



Battery model coefficient generator:

ZN/CL/3.3

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	41.43	4.143	2.30259	1.42142
20	41.94	2.097	2.99573	.740508
30	41.26	1.37533	3.4012	.318696
40	40.24	1.006	3.68888	5.98197E-03
50	39.04	.7808	3.91202	-.247436
60	37.71	.6285	4.09435	-.464419
70	36.28	.518286	4.2485	-.657229
80	34.73	.434125	4.38203	-.834423
90	33.05	.367222	4.49981	-1.00179
100	31.2	.312	4.60517	-1.16475

RESULTS -----

ln(Pd) = 3.69598 + -.878004 *ln(tau) + -.0750732 *[ln(tau)]^2

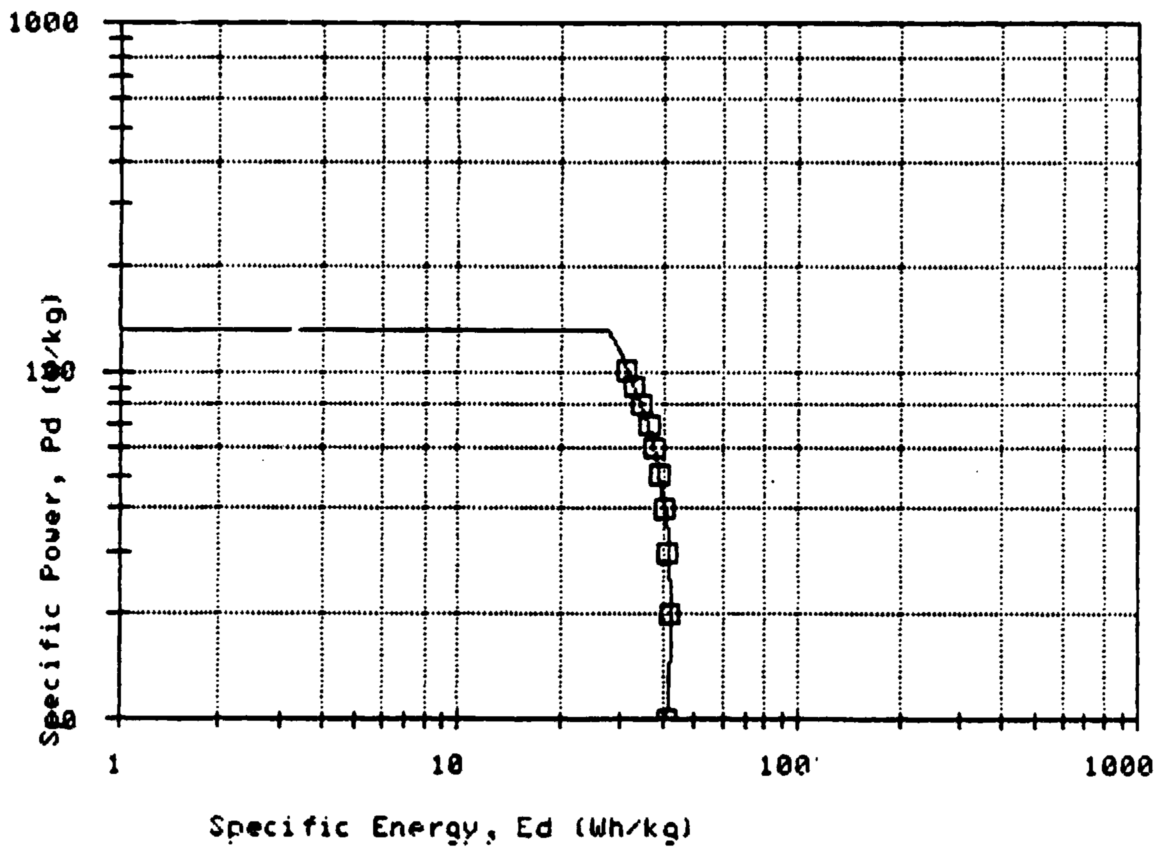
CH1 = 3.69598
CH2 = -.878004
CH3 = -.0750732

Sum of the squares of the residuals = 4.63915F-04
Standard error estimate = 7.61508E-03
Coefficient of determination = .999904

ELVEC battery CH coefficient curve plot.....

For battery: ZN/CL/3.3

CH-1 = 3.69598 Pdmax = 130
CH-2 = -.878004
CH-3 = -.0750732



Battery model coefficient generator:

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FE/AIR/1.0

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	106.28	10.628	2.30259	2.36349
20	109.38	5.469	2.99573	1.6991
30	108.46	3.61533	3.4012	1.28518
40	106.33	2.65825	3.68888	.977668
50	103.56	2.0712	3.91202	.728128
60	100.34	1.67233	4.09435	.51422
70	96.69	1.38129	4.2485	.323015
80	92.55	1.15688	4.38203	.145722
90	87.8	.975556	4.49981	-.0247479
100	82.11	.8211	4.60517	-.19711

RESULTS -----

ln(Pd) = 4.48115 + -.723875 *ln(tau) + -.0850794 *[ln(tau)]^2

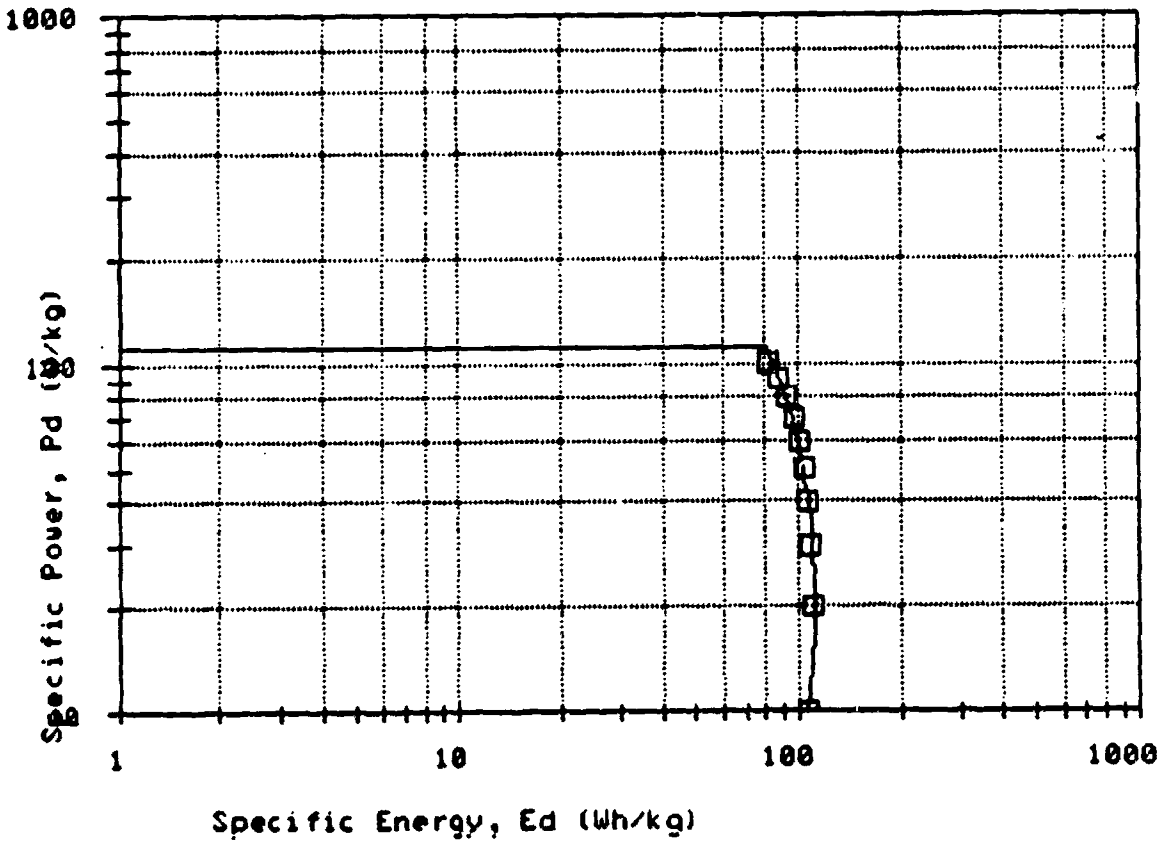
CH1 = 4.48115
CH2 = -.723875
CH3 = -.0850794

Sum of the squares of the residuals = 7.24412E-04
Standard error estimate = 9.51585E-03
Coefficient of determination = .99985

ELVEC battery CH coefficient curve plot.....

For battery: FE/AIR/1.0

CH-1 = 4.48115 Pdmax = 110
CH-2 = -.723875
CH-3 = -.0850794



Battery model coefficient generator:

FE/AIR/2.1

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	66.39	6.639	2.30259	1.89296
20	67.83	3.3915	2.99573	1.22127
30	67.21	2.24033	3.4012	.806625
40	65.99	1.64975	3.68888	.500624
50	64.46	1.2892	3.91202	.254022
60	62.73	1.0455	4.09435	.0444953
70	60.81	.868714	4.2485	-.140741
80	58.7	.73375	4.38203	-.309587
90	56.37	.626333	4.49981	-.467872
100	53.77	.5377	4.60517	-.620455

RESULTS -----

ln(Pd) = 4.12545 + -.833583 *ln(tau) + -.0698404 *[ln(tau)]^2

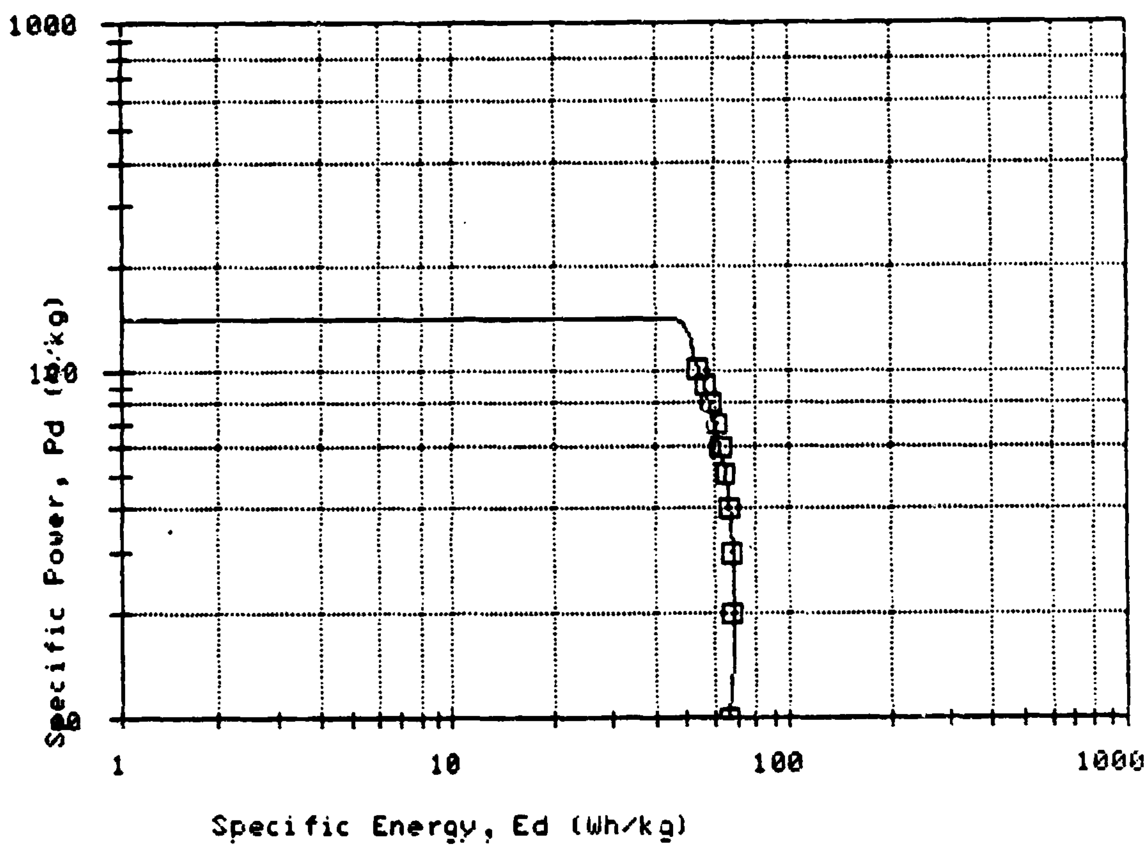
CH1 = 4.12545
CH2 = -.833583
CH3 = -.0698404

Sum of the squares of the residuals = 3.64821E-04
Standard error estimate = 6.75297E-03
Coefficient of determination = .999925

ELVEC battery CH coefficient curve plot.....

For battery: FE/AIR/2.1

CH-1 = 4.12545 Pdmax = 140
CH-2 = -.833583
CH-3 = -.0698404



Battery model coefficient generator:

FE/ATR/2.4

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	66.14	6.614	2.30259	1.88919
20	67.72	3.386	2.99573	1.21965
30	67.29	2.243	3.4012	.807814
40	66.29	1.65725	3.68888	.50516
50	65.01	1.3002	3.91202	.262518
60	63.55	1.05917	4.09435	.0574824
70	61.94	.884857	4.2485	-.122329
80	60.2	.7525	4.38203	-.284354
90	58.31	.647889	4.49981	-.434036
100	56.27	.5627	4.60517	-.575009

RESULTS -----

ln(Pd) = 4.13931 + -.858481 *ln(tau) + -.0612641 *[ln(tau)]^2

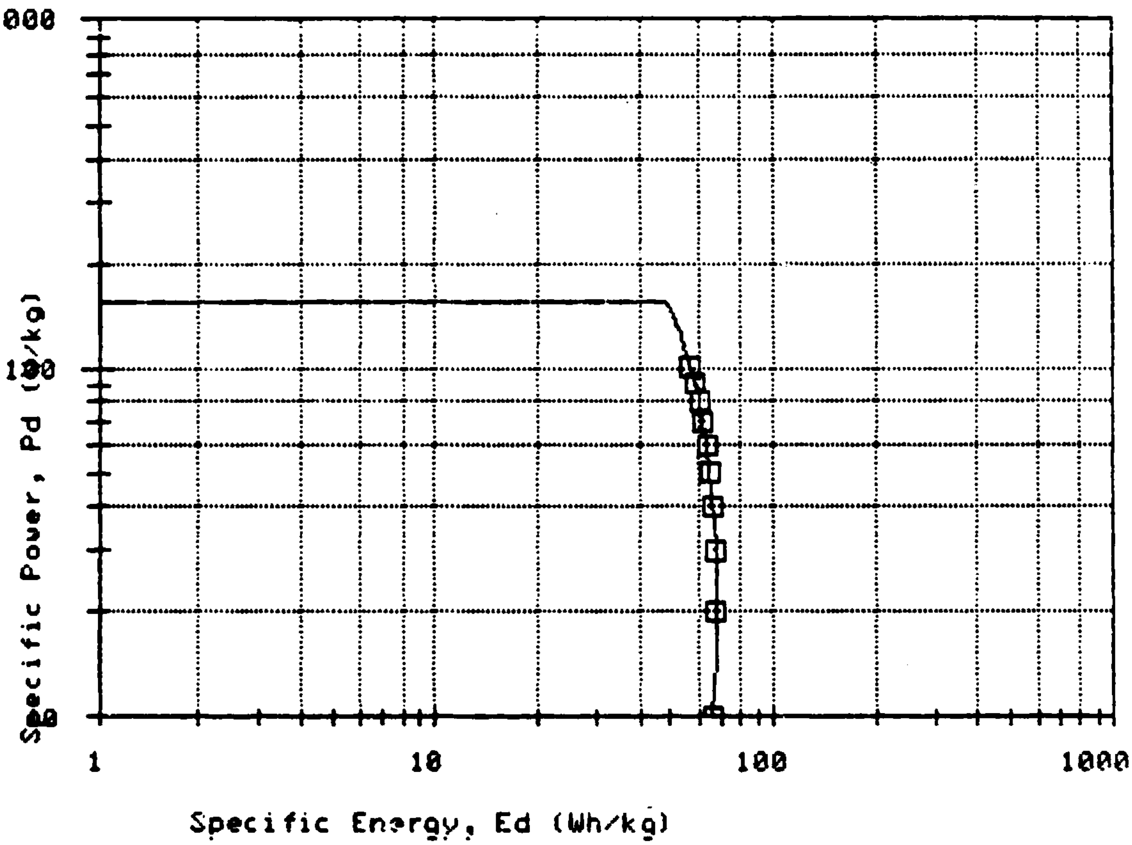
CH1 = 4.13931
CH2 = -.858481
CH3 = -.0612641

Sum of the squares of the residuals = 1.87778E-04
Standard error estimate = 4.84481E-03
Coefficient of determination = .999961

ELVEC battery CH coefficient curve plot.....

For battery: FE/AIR/2.4

CH-1 = 4.13931 Pdmax = 157
CH-2 = -.858481
CH-3 = -.0612641



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Battery model coefficient generator:

FE/AIR/3.3

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	51.66	5.166	2.30259	1.6421
20	52.34	2.617	2.99573	.962029
30	51.79	1.72633	3.4012	.546
40	50.9	1.2725	3.68888	.240984
50	49.84	.9968	3.91202	-3.205E-03
60	48.67	.811167	4.09435	-.209282
70	47.41	.677286	4.2485	-.389662
80	46.07	.575875	4.38203	-.551865
90	44.64	.496	4.49981	-.701179
100	43.12	.4312	4.60517	-.841183

RESULTS -----

ln(Pd) = 3.90664 + -.886569 *ln(tau) + -.0563951 *[ln(tau)]^2

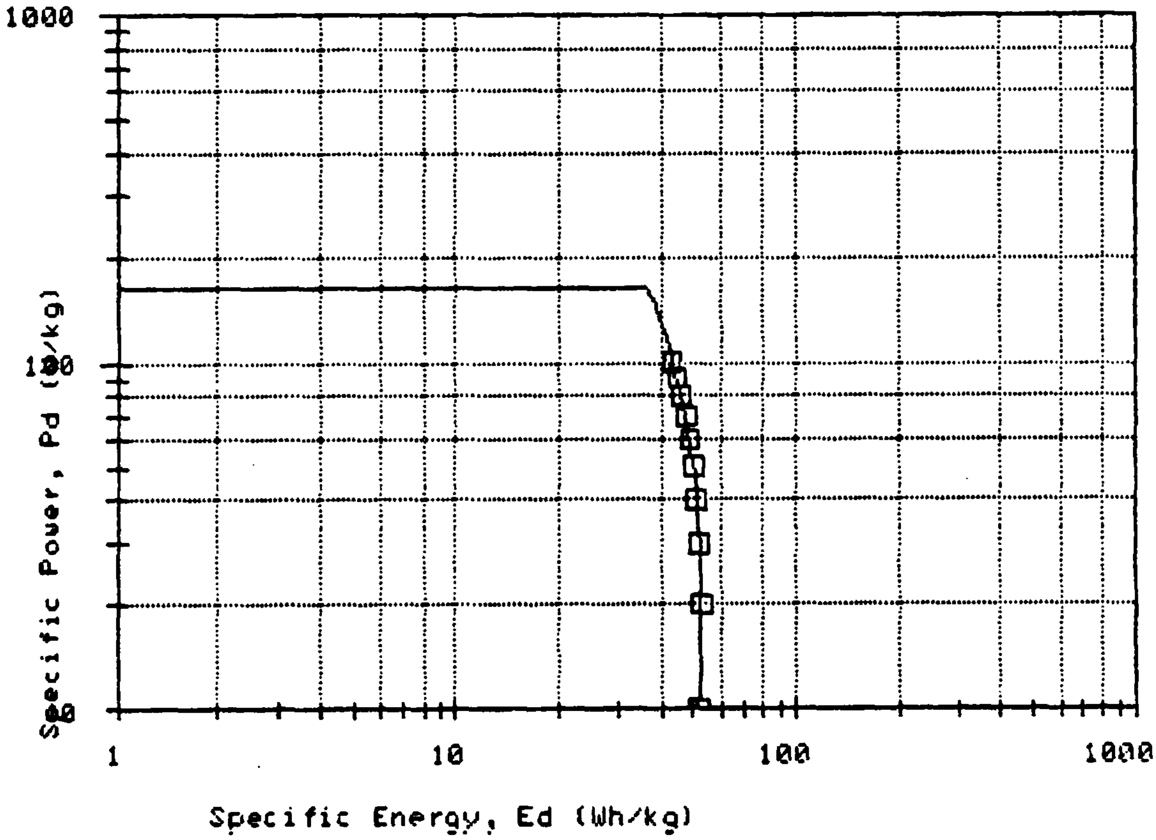
CH1 = 3.90664
CH2 = -.886569
CH3 = -.0563951

Sum of the squares of the residuals = 1.87741E-04
Standard error estimate = 4.84434E-03
Coefficient of determination = .999961

ELVEC battery CH coefficient curve plot.....

For battery: FE/AIR/3.3

CH-1 = 3.90664 Pdmax = 165
CH-2 = -.886569
CH-3 = -.0563951



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Battery model coefficient generator:

LI/MS1.0

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	102	5.1	2.99573	1.62924
60	88	1.46667	4.09435	.382992
100	72	.72	4.60517	-.328504

RESULTS -----

ln(Pd) = 4.37983 + -.713407 *ln(tau) + -.0835533 *[ln(tau)]^2

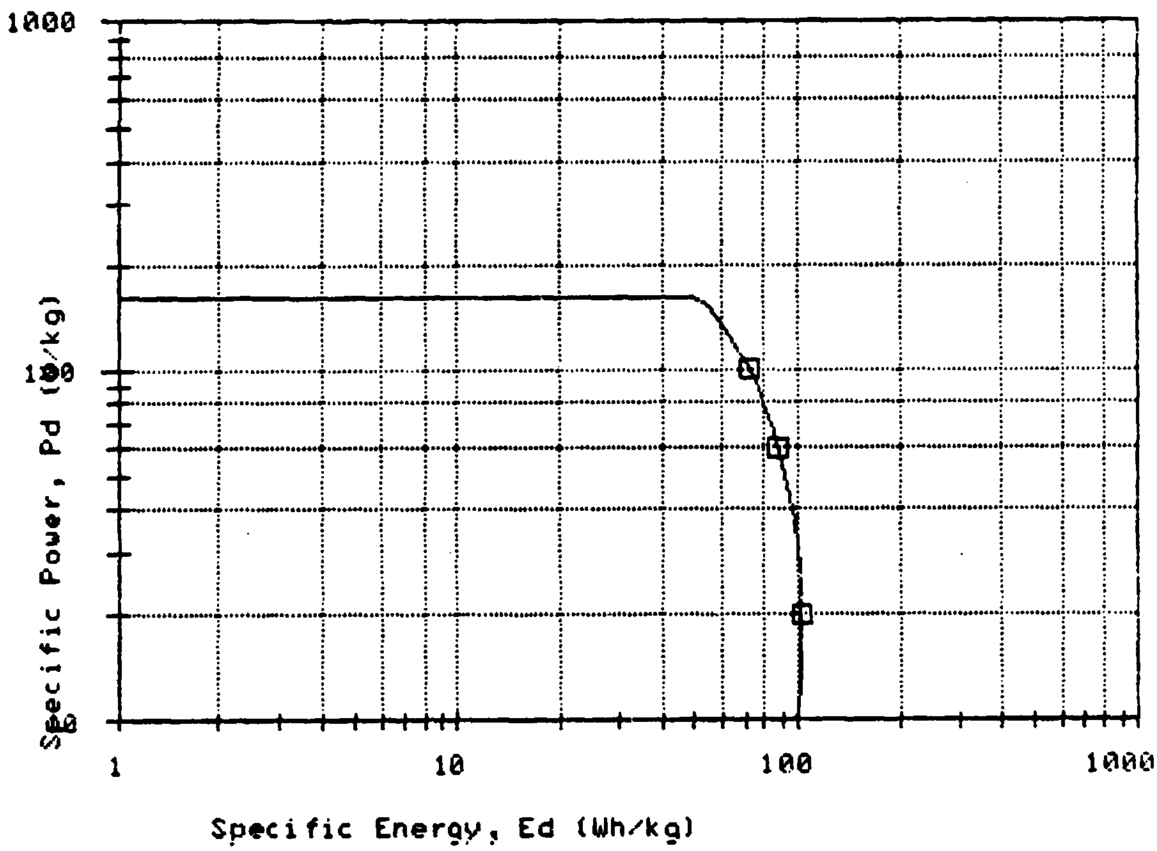
CH1 = 4.37983
CH2 = -.713407
CH3 = -.0835533

Sum of the squares of the residuals = 4.54747E-13
Standard error estimate = 6.74349E-07
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: LI/MS1.0

CH-1 = 4.37983   Pdmax = 161
CH-2 = -.713407
CH-3 = -.0835533



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Battery model coefficient generator:

LI/MS2.1 - 2.4

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	81	4.05	2.99573	1.39872
60	70	1.16667	4.09435	.154151
100	57	.57	4.60517	-.562119

RESULTS -----

ln(Pd) = 4.21177 + -.748451 *ln(tau) + -.0864695 *[ln(tau)]^2

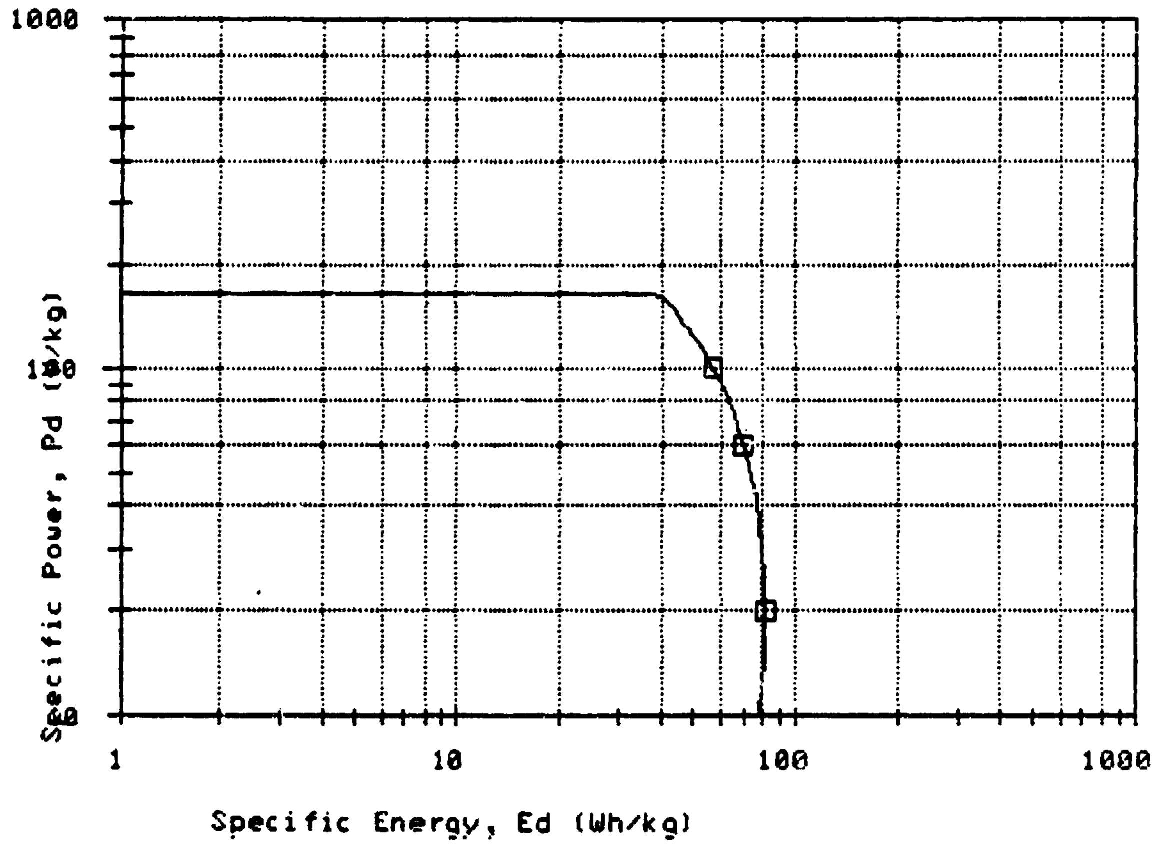
CH1 = 4.21177
CH2 = -.748451
CH3 = -.0864695

Sum of the squares of the residuals = 7.38965E-13
Standard error estimate = 8.59631E-07
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: LI/MS2.1

CH-1 = 4.21177 Pdmax = 165
CH-2 = -.748451
CH-3 = -.0864695



Battery model coefficient generator:

LI/MS3.3

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	71	3.55	2.99573	1.26695
60	63	1.05	4.09435	.0487902
100	53	.53	4.60517	-.634878

RESULTS -----

ln(Pd) = 4.13332 + -.79485 *ln(tau) + -.081334 *[ln(tau)]^2

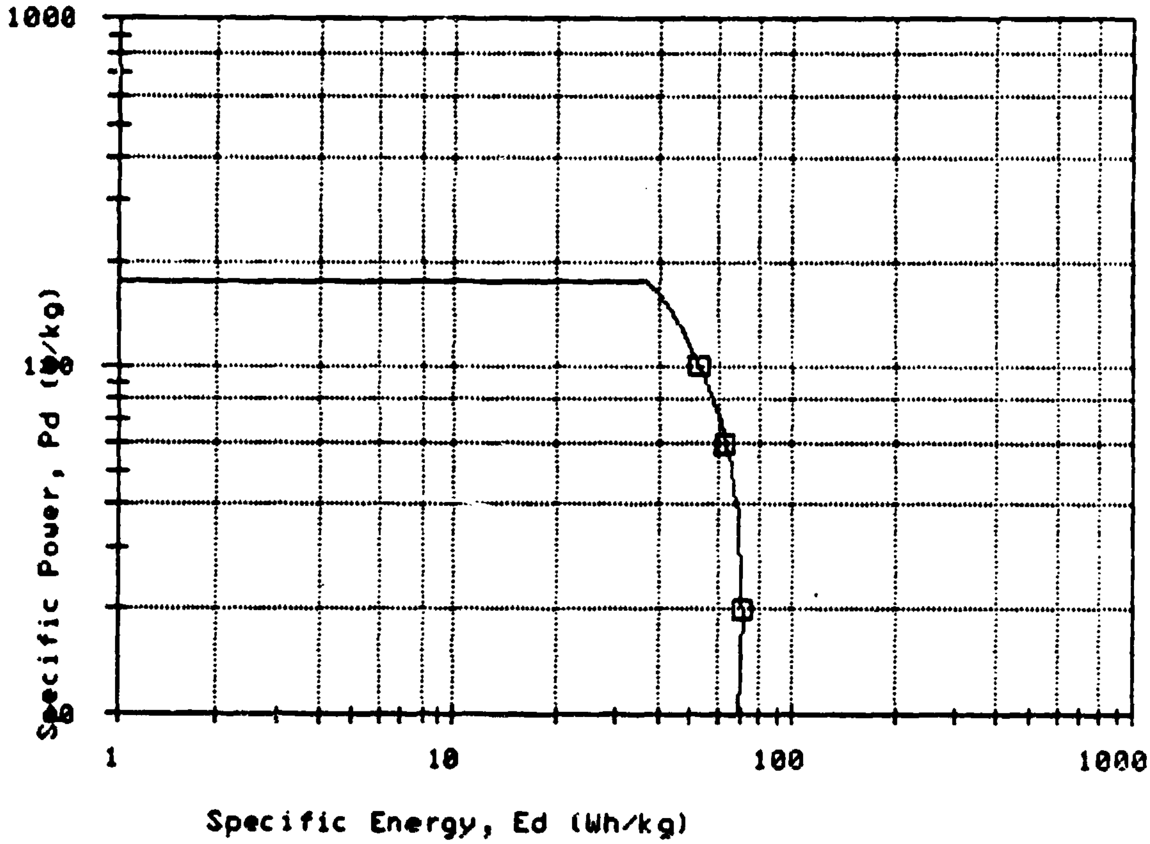
CH1 = 4.13332
CH2 = -.79485
CH3 = -.081334

Sum of the squares of the residuals = 1.81899E-12
Standard error estimate = 1.3487E-06
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: LI/MS3.3

CH-1 = 4.13332 Pdmax = 175
CH-2 = -.79485
CH-3 = -.081334



Battery model coefficient generator:

NA/S/1.0

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	123.3	12.33	2.30259	2.51204
20	120.53	6.0265	2.99573	1.79617
30	117.69	3.923	3.4012	1.36686
40	114.78	2.8695	3.68888	1.05414
50	111.78	2.2356	3.91202	.80451
60	108.67	1.81117	4.09435	.593971
70	105.46	1.50657	4.2485	.409837
80	102.11	1.27638	4.38203	.244024
90	98.61	1.09567	4.49981	.091363
100	94.92	.9492	4.60517	-.0521356

RESULTS -----

ln(Pd) = 4.57375 + -.790541 *ln(tau) + -.0460973 *[ln(tau)]^2

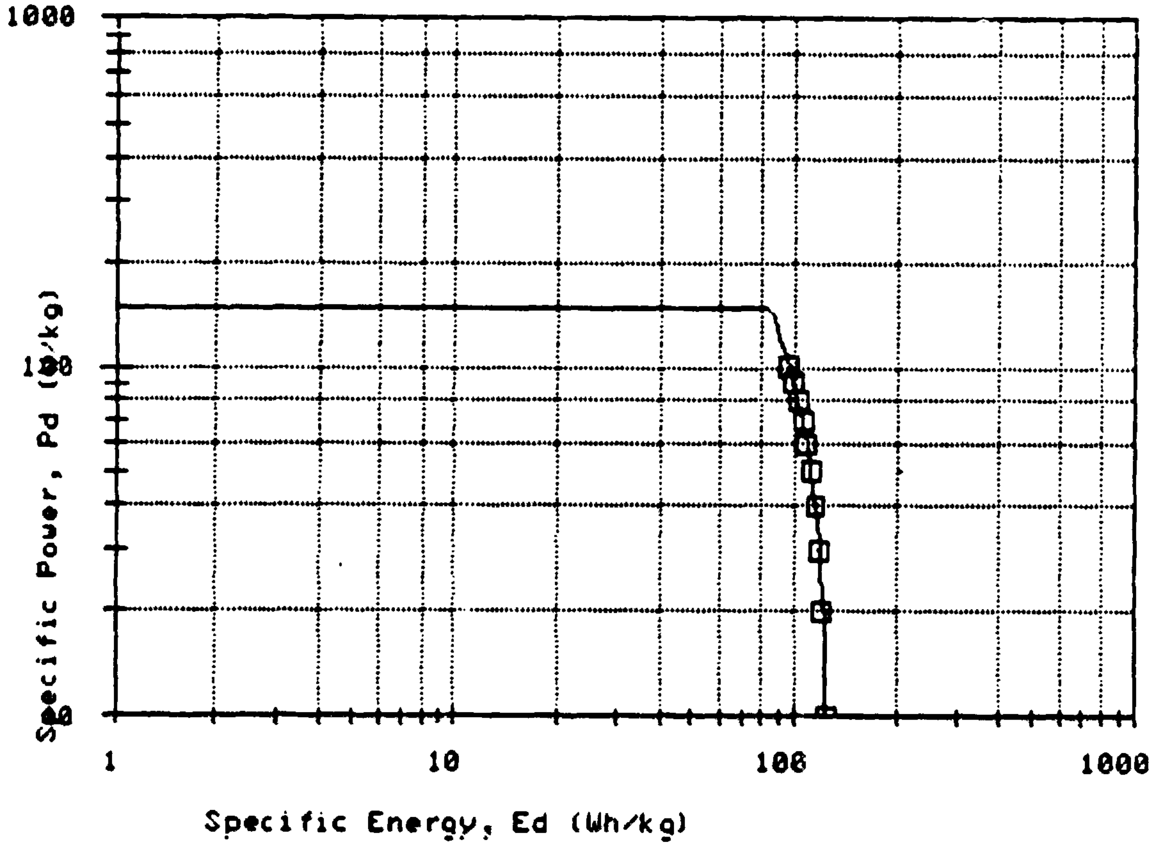
CH1 = 4.57375
CH2 = -.790541
CH3 = -.0460973

Sum of the squares of the residuals = 3.64[illegible]E-04
Standard error estimate = 6.74657E-03
Coefficient of determination = .999925

ELVEC battery CH coefficient curve plot.....

For battery: NA/S/1.0

CH-1 = 4.57375   Pdmax = 148
CH-2 = -.790541
CH-3 = -.0460973



Battery model coefficient generator:

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NA/S/2.1

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	88.16	8.816	2.30259	2.17657
20	86.93	4.3465	2.99573	1.46937
30	85.67	2.85567	3.4012	1.04931
40	84.38	2.1095	3.68888	.746451
50	83.04	1.6608	3.91202	.5073
60	81.65	1.36083	4.09435	.308097
70	80.21	1.14586	4.2485	.136153
80	78.72	.984	4.38203	-.0161292
90	77.16	.857333	4.49981	-.153928
100	75.53	.7553	4.60517	-.28064

RESULTS -----

ln(Pd) = 4.36547 + -.884152 *ln(tau) + -.0299432 *[ln(tau)]^2

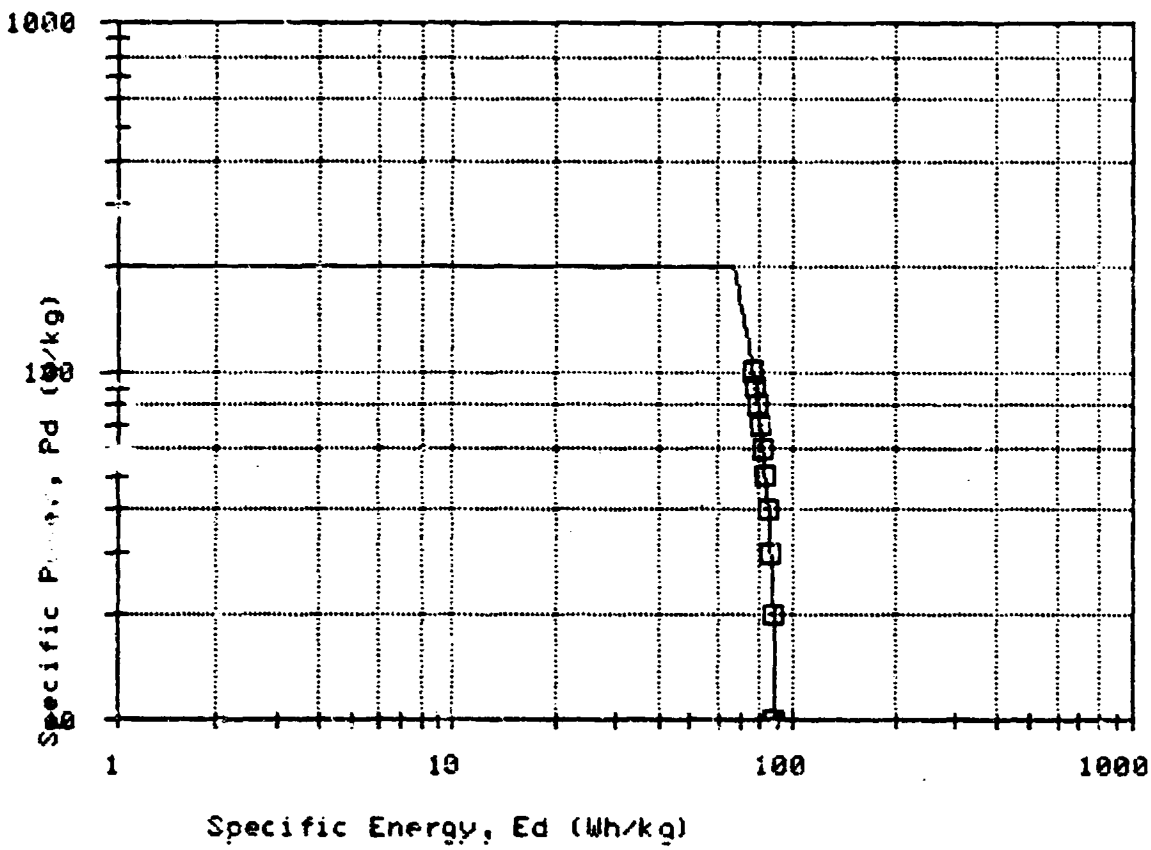
CH1 = 4.36547
CH2 = -.884152
CH3 = -.0299432

Sum of the squares of the residuals = 1.43137E-04
Standard error estimate = 4.22991E-03
Coefficient of determination = .99997

ELVEC battery CH coefficient curve plot.....

For battery: NA/S/2.1

CH-1 = 4.36547 Pdmax = 199
CH-2 = -.884152
CH-3 = -.0299432



Battery model coefficient generator:

NA/S/2.4

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	84.17	8.417	2.30259	2.13025
20	83.06	4.153	2.99573	1.42383
30	81.92	2.73067	3.4012	1.00455
40	80.75	2.01875	3.68888	.702479
50	79.54	1.5908	3.91202	.464237
60	78.3	1.305	4.09435	.266203
70	77.03	1.10043	4.2485	.0956998
80	75.71	.946375	4.38203	-.0551162
90	74.34	.826	4.49981	-.19116
100	72.92	.7292	4.60517	-.315807

RESULTS -----

ln(Pd) = 4.3308 + -.894503 *ln(tau) + -.0276968 *[ln(tau)]^2

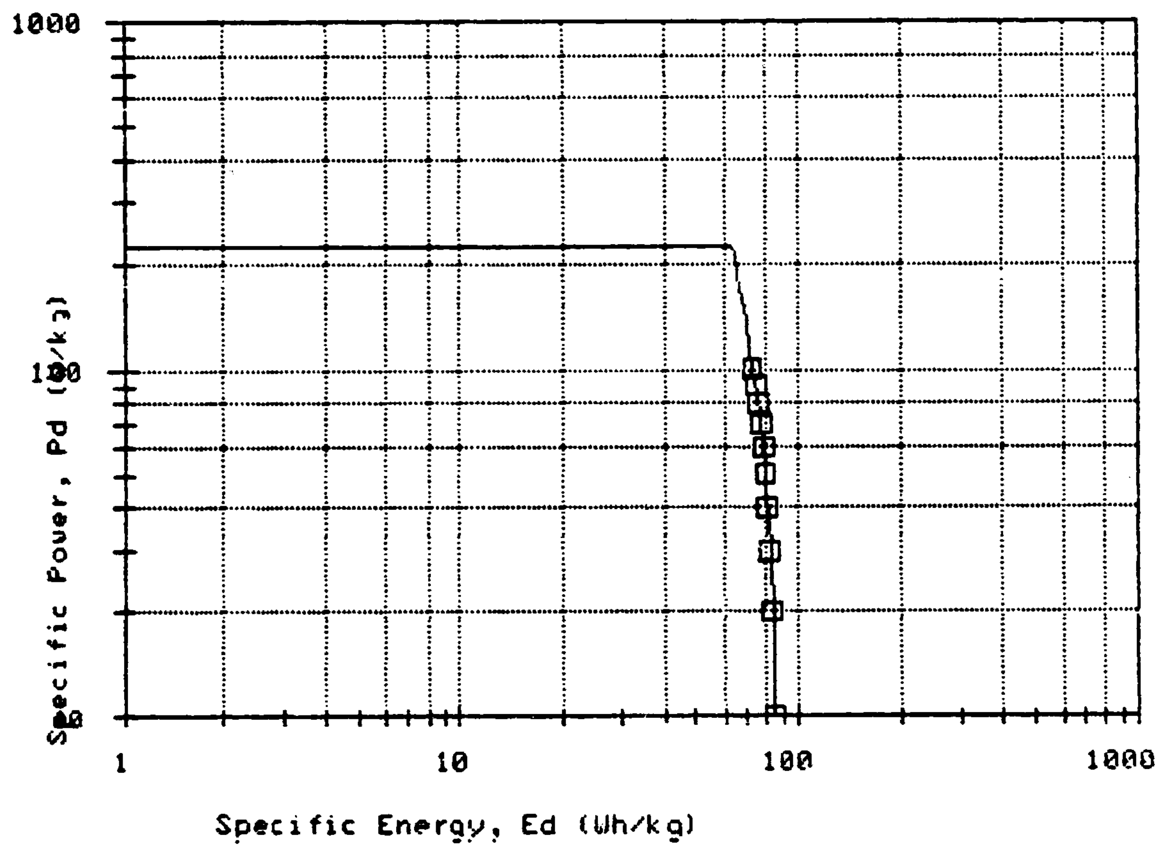
CH1 = 4.3308
CH2 = -.894503
CH3 = -.0276968

Sum of the squares of the residuals = 1.12011E-04
Standard error estimate = 3.74184E-03
Coefficient of determination = .999977

ELVEC battery CH coefficient curve plot.....

For battery: NA/S/2.4

CH-1 = 4.3308 Pdmax = 224
CH-2 = -.894503
CH-3 = -.0276968



Battery model coefficient generator:

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NA/S/3.3

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	74.02	7.402	2.30259	2.00175
20	73.04	3.652	2.99573	1.29528
30	72.04	2.40133	3.4012	.876024
40	71.02	1.7755	3.68888	.574082
50	69.97	1.3994	3.91202	.336044
60	68.89	1.14817	4.09435	.138167
70	67.78	.968286	4.2485	-.0322278
80	66.64	.833	4.38203	-.182722
90	65.45	.727222	4.49981	-.318523
100	64.22	.6422	4.60517	-.442855

RESULTS -----

ln(Pd) = 4.21601 + -.902732 *ln(tau) + -.0272804 *[ln(tau)]^2

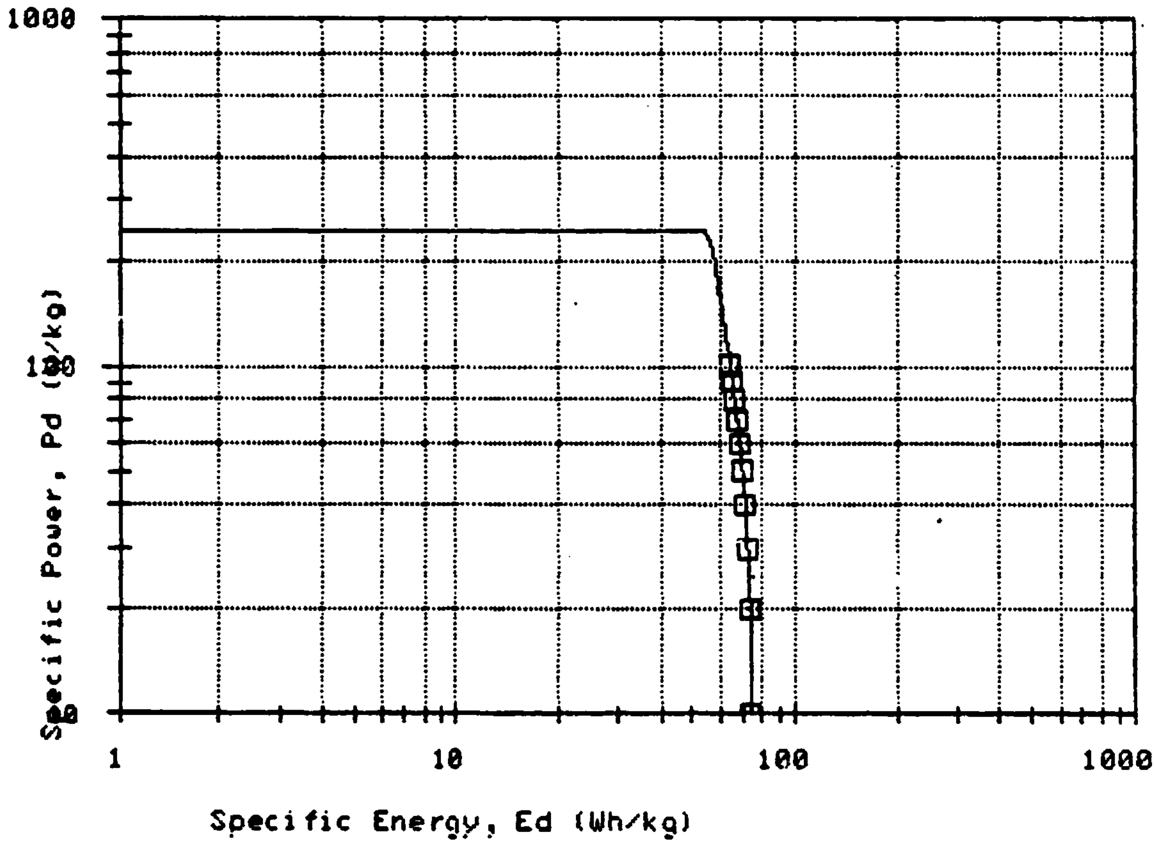
CH1 = 4.21601
CH2 = -.902732
CH3 = -.0272804

Sum of the squares of the residuals = 1.08422E-04
Standard error estimate = 3.68141E-03
Coefficient of determination = .999978

ELVEC battery CH coefficient curve plot.....

For battery: NA/S/3.3

CH-1 = 4.21601 Pdmax = 244
CH-2 = -.902732
CH-3 = -.0272804



Battery model coefficient generator:

A/AIR/PRES W/IMPR SELF-DISCH

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	158	7.9	2.99573	2.06686
60	158	2.63333	4.09435	.968251
80	158	1.975	4.38203	.680569
100	151	1.51	4.60517	.41211
157	126	.802548	5.05625	-.219964

RESULTS -----

ln(Pd) = 4.9078 + -.723055 *ln(tau) + -.0984402 *[ln(tau)]^2

CH1 = 4.9078
CH2 = -.723055
CH3 = -.0984402

Sum of the squares of the residuals = 7.73907E-04
Standard error estimate = .0160614
Coefficient of determination = .999676

ELVEC battery CH coefficient curve plot.....

For battery: Al/AIR/PRES W/IMPR SELF-DISCH

CH-1 = 4.9078 Pdmax = 157
CH-2 = -.723055
CH-3 = -.0984402

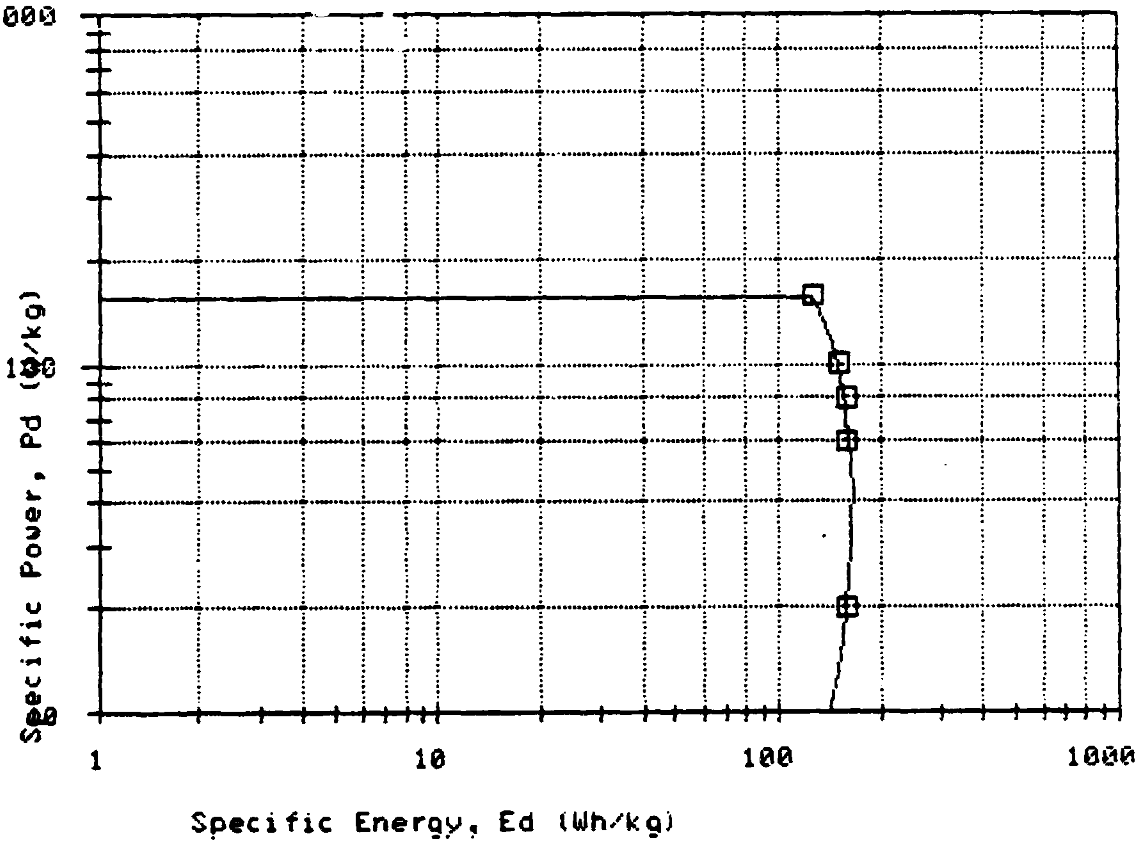


Table N-1. Battery Projections by Review Board

Battery Type	Energy (Wh/kg @20W/kg)	Power (30-s W/kg @10% SOC)	Annual Efficiency (%)	Cycle Life	OEM Cost* a	b	c
Pb/Acid	38-45	80-100	75	750	43	9	400
Bip.Pb/Acid	50	275	85	750	80		
Ni/Fe	48-56	75-110	58	1500	100	12	800
Ni/Zn	60	155	70	600	130		
Zn/Br2	40-67	52-94	46	750	20	10	700
Zn/Cl2	42-89	80-115	48	1500	10	45	1150
Fe/Air	52-109	102-146	50	500	8	25	700
Li/FeS	72-102	90-107	60	750	70	10	750
Na/S	73-121	129-220	66	750	25	45	1000
Al/Air	158	157	18**	3000***		42	

* OEM Costs in 1982$ = a*kWh + b*kW + c (Symons equation) , numbers listed are the review board's low estimates

** Source energy

*** Life of air cathode-3000 cold starts, equivalent to 4 years

Table N-2. Battery Projections by Developers

Battery Type	Energy (Wh/kg @20W/kg)	Power (30-s W/kg @10% SOC)	Annual Efficiency (%)	Cycle Life	OEM Cost*
Pb/Acid	38-45	80-100	75	800	$ 53/kWh
Ni/Fe	50-56	100-130	72	1500	130/kWh
Ni/Zn	60	155	70	600	130/kWh
Zn/Br2	40-67	52-94	56	750	40/kWh
Zn/Cl2	50-110	103-154	53	1500	61-81/kW
Fe/Air	98-195	181-309	68	500	21-25/kW
Li/FeS	87-136	90-131	65	1000	99-115/kWh
Na/S	73-132	143-220	75	800**	63-97/kW
Al/Air	218	218	32	3000***	32/kW

* Equivalent values calculated from cost estimates of complete battery systems in some instances

** Surrogate for replacement of 25% of the cells in 1000 cycles

*** Life of air cathode-3000 cold starts, equivalent to 4 years

APPENDIX O

BATTERY DISCHARGE MODELS
BASED ON BATTERY DESIGN REPORTS

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Battery model coefficient generator:

NI/FE 1.0, 2.1, 2.4

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	58	5.8	2.30259	1.75786
20	56	2.8	2.99573	1.02962
60	46	.766667	4.09435	-.265703
100	31	.31	4.60517	-1.17118

RESULTS -----

ln(Pd) = 3.8825 + -.73727 *ln(tau) + -.0959177 *[ln(tau)]^2

CH1 = 3.8825
CH2 = -.73727
CH3 = -.0959177

Sum of the squares of the residuals = 1.43249E-03
Standard error estimate = .0267628
Coefficient of determination = .999561

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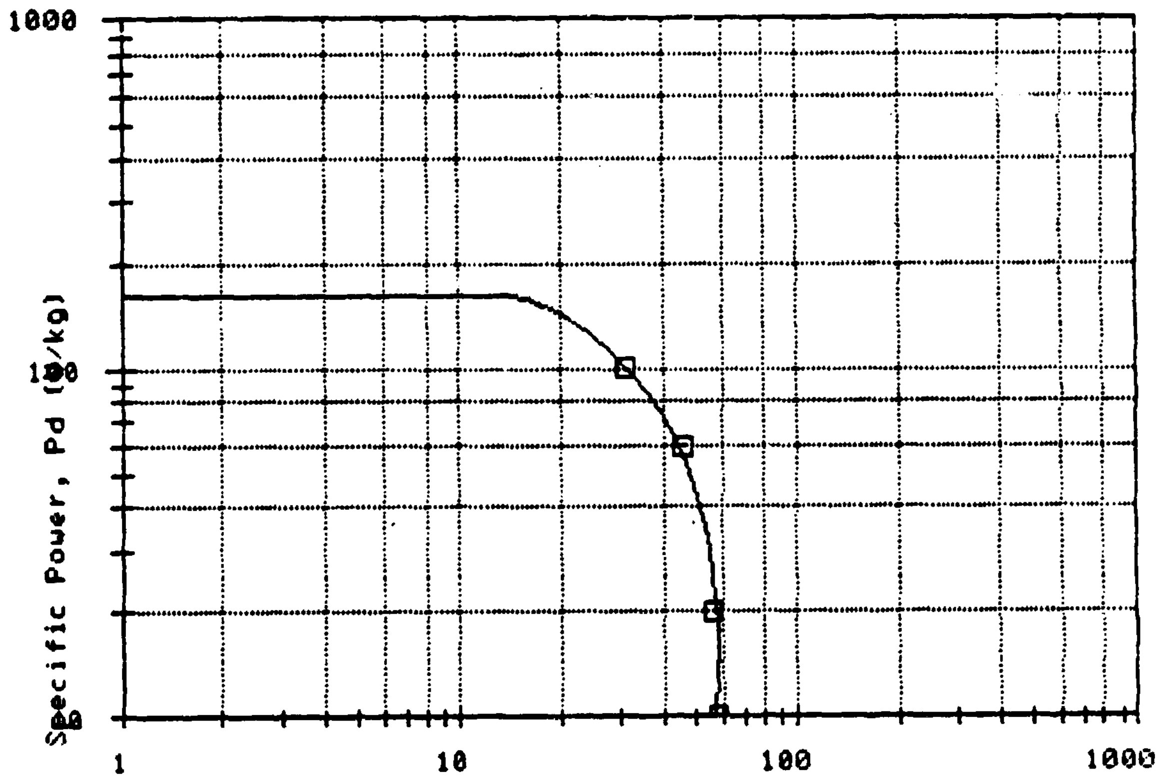
ELVEC battery CH coefficient curve plot.....

For battery: NI/FE 1.0, 2.1, 2.4

CH-1 = 3.8825 Pdmax = 160
CH-2 = -.73727
CH-3 = -.0959177



Battery model coefficient generator:

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NI/FE 3.3

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
10	52	5.2	2.30259	1.64866
20	50	2.5	2.99573	.916291
60	44	.733333	4.09435	-.310155
100	37	.37	4.60517	-.994252

RESULTS -----

ln(Pd) = 3.8239 + -.842842 *ln(tau) + -.050693 *[ln(tau)]^2

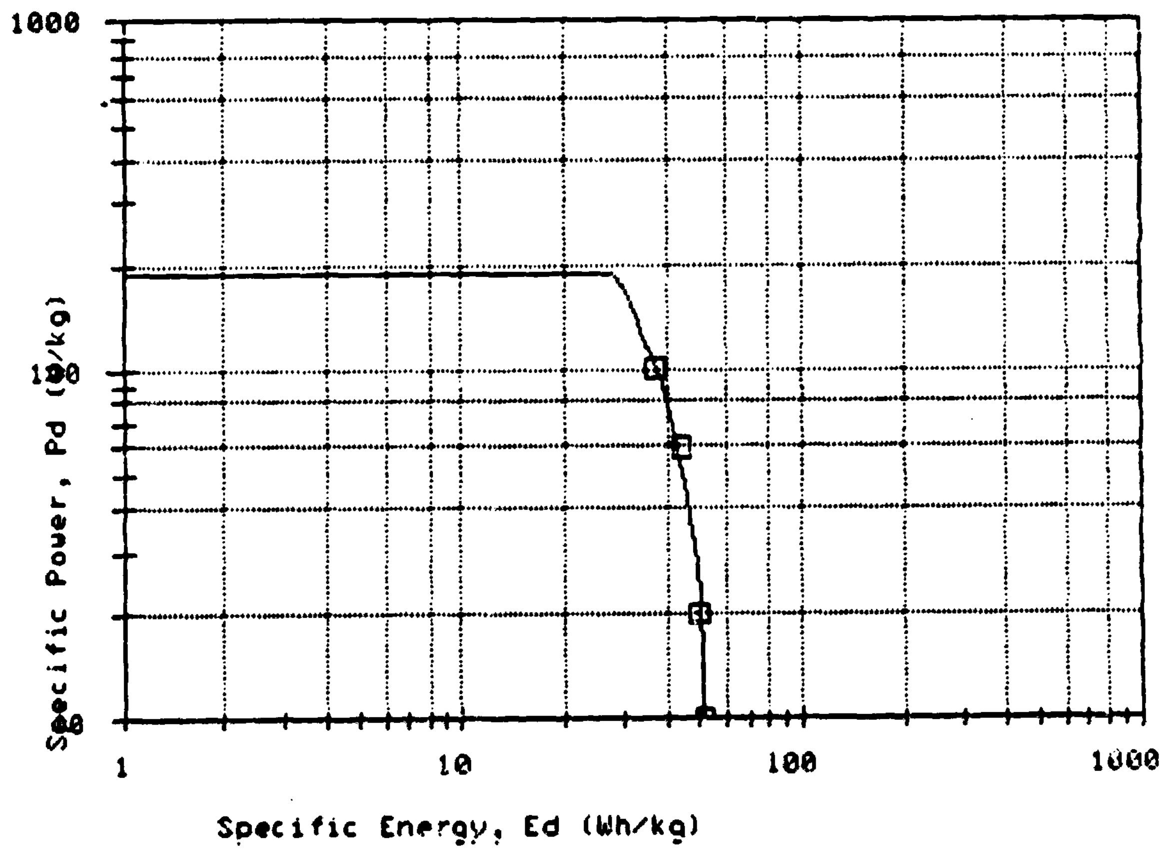
CH1 = 3.8239
CH2 = -.842842
CH3 = -.050693

Sum of the squares of the residuals = 4.50989E-04
Standard error estimate = .0150165
Coefficient of determination = .999862

ELVEC battery CH coefficient curve plot.....

For battery: NI/FE 3.3

CH-1 = 3.8239 Pdmax = 190
CH-2 = -.842842
CH-3 = -.050693



Battery model coefficient generator:

ZN/CL 1.0

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	110	5.5	2.99573	1.70475
60	100	1.66667	4.09435	.510826
100	85	.85	4.60517	-.162519

RESULTS -----

ln(Pd) = 4.48906 + -.728524 *ln(tau) + -.0864971 *[ln(tau)]^2

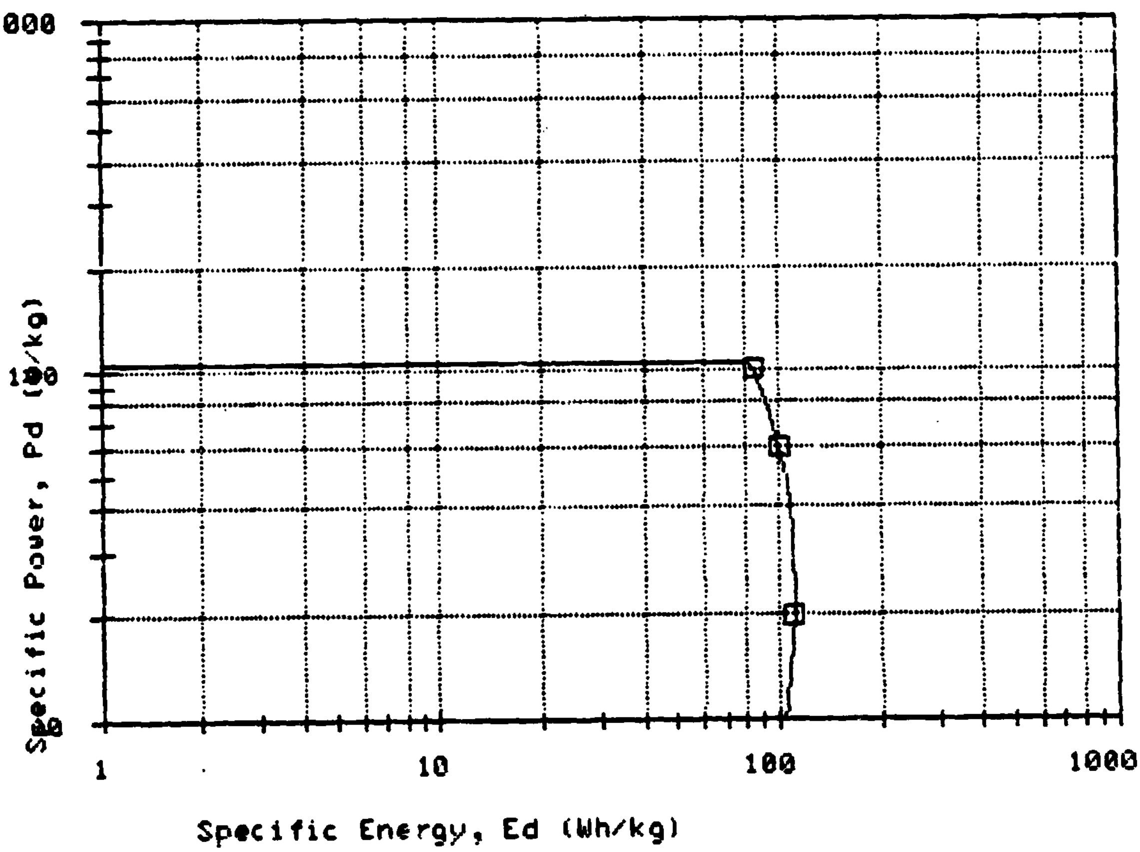
CH1 = 4.48906
CH2 = -.728524
CH3 = -.0864971

Sum of the squares of the residuals = 3.66072E-11
Standard error estimate = 6.05039E-06
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: ZN/CL 1.0

CH-1 = 4.48906 Pdmax = 105
CH-2 = -.728524
CH-3 = -.0864971



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Battery model coefficient generator:

ZN/CL 2.1

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	66	3.3	2.99573	1.19392
60	60	1	4.09435	0
100	55	.55	4.60517	-.597837

RESULTS -----

ln(Pd) = 4.09435 + -.876383 *ln(tau) + -.0366745 *[ln(tau)]^2

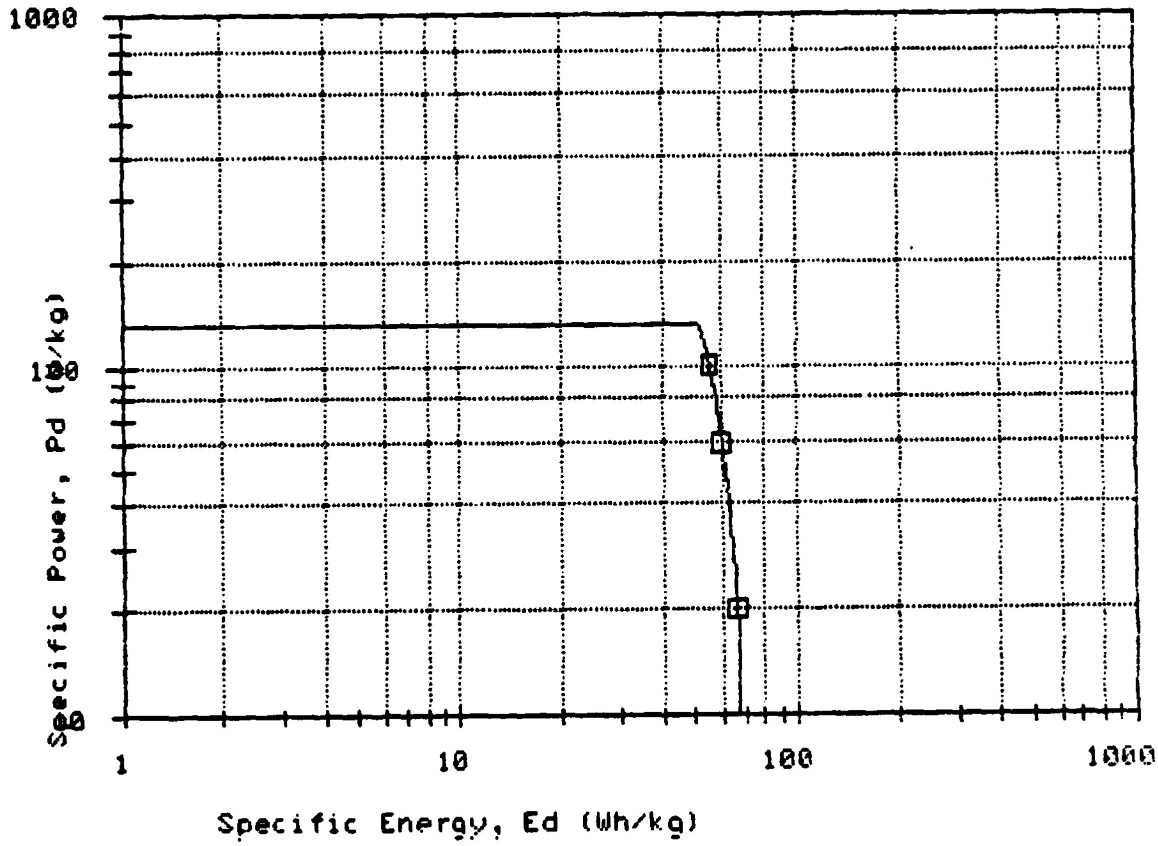
CH1 = 4.09435
CH2 = -.876383
CH3 = -.0366745

Sum of the squares of the residuals = 9.66338E-13
Standard error estimate = 9.83026E-07
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: ZN/CL 2.1

CH-1 = 4.09435 Pdmax = 130
CH-2 = -.876383
CH-3 = -.0366745



Battery model coefficient generator:

ZN/CL 2.4

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	65	3.25	2.99573	1.17866
60	61	1.01667	4.09435	.0165293
100	56	.56	4.60517	-.579819

RESULTS -----

ln(Pd) = 4.10899 + -.885019 *ln(tau) + -.0504766 *[ln(tau)]^2

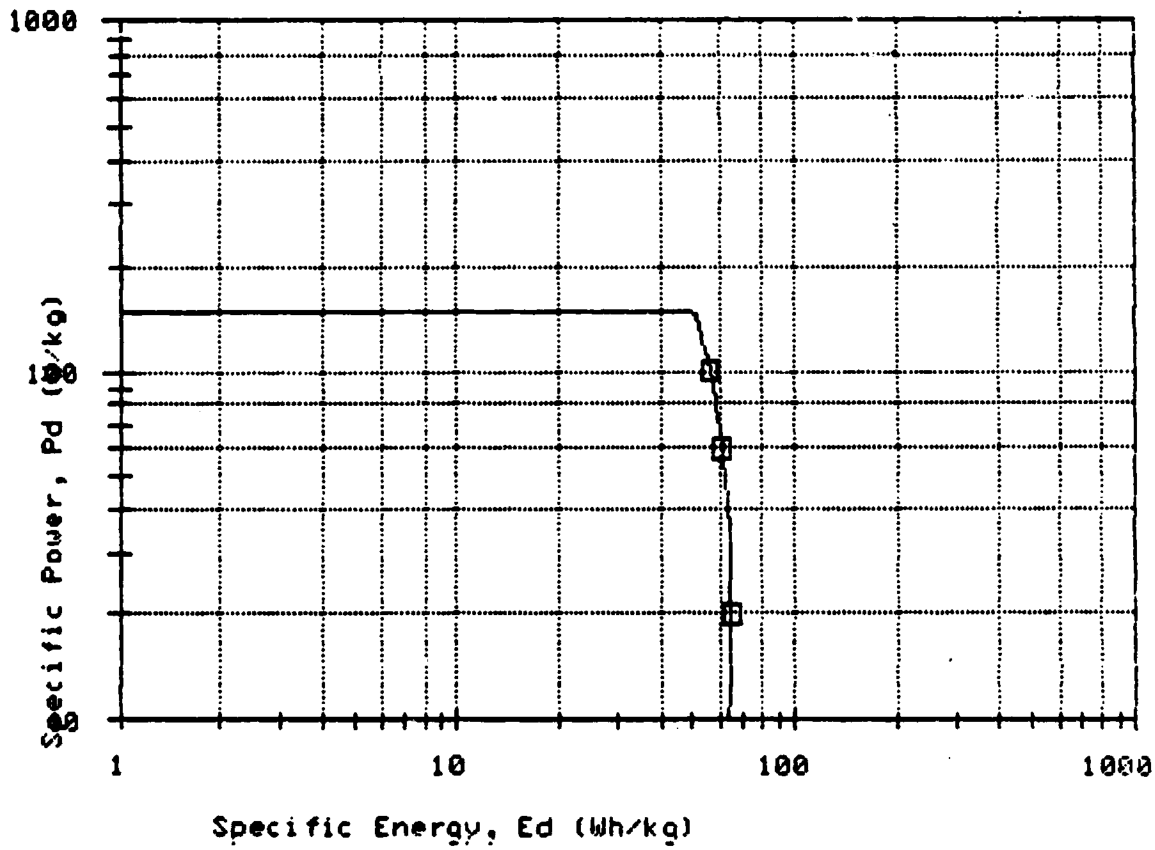
CH1 = 4.10899
CH2 = -.885019
CH3 = -.0504766

Sum of the squares of the residuals = 1.81899E-12
Standard error estimate = 1.3487E-06
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: ZN/CL 2.4

CH-1 = 4.10899 Pdmax = 147
CH-2 = -.885019
CH-3 = -.0504766



Battery model coefficient generator:

ZN/CL 3.3

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	50	2.5	2.99573	.916291
60	47	.783333	4.09435	-.244197
100	44	.44	4.60517	-.820981

RESULTS -----

ln(Pd) = 3.87103 + -.923069 *ln(tau) + -.035132 *[ln(tau)]^2

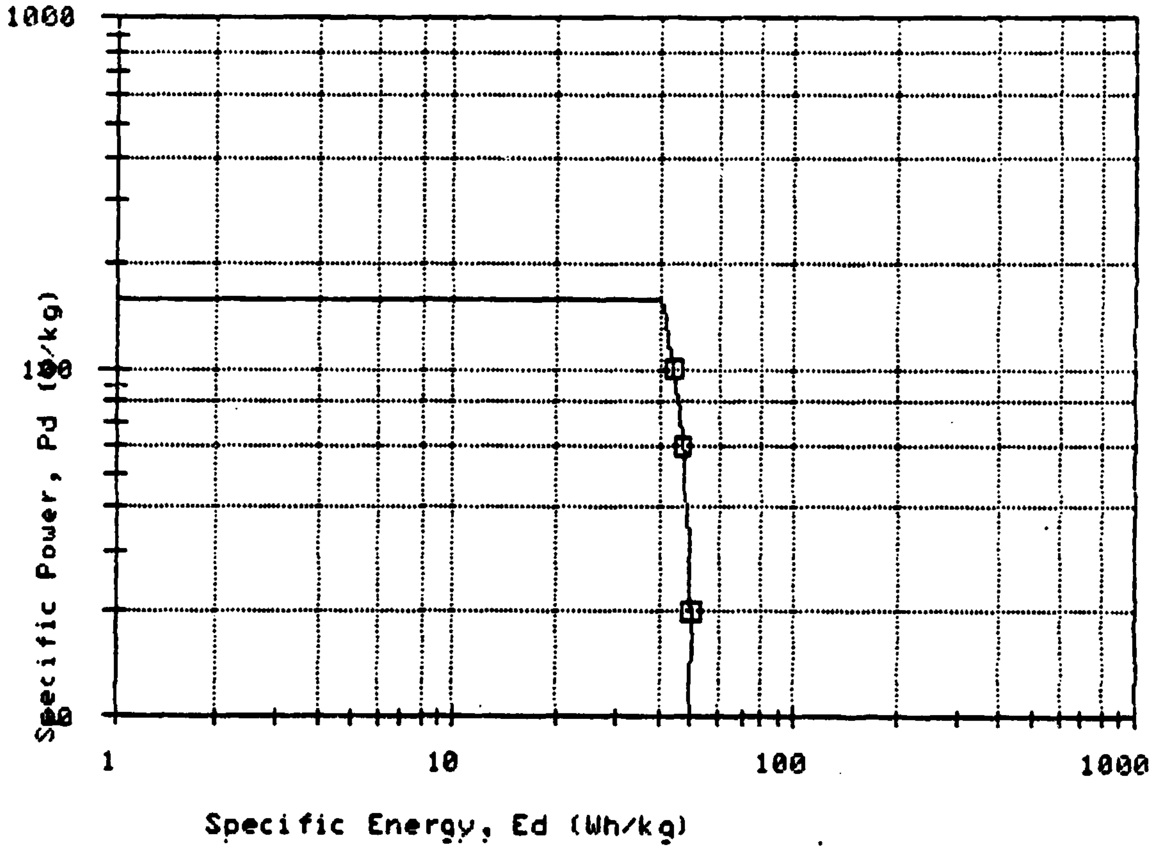
CH1 = 3.87103
CH2 = -.923069
CH3 = -.035132

Sum of the squares of the residuals = 9.66339E-13
Standard error estimate = 9.83026E-07
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: ZN/CL 3.3

CH-1 = 3.87103 Pdmax = 158
CH-2 = -.923069
CH-3 = -.035132



Battery model coefficient generator:

FE/AIR 1.0

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	195	9.75	2.99573	2.27727
60	182	3.03333	4.09435	1.10966
100	167	1.67	4.60517	.512824

RESULTS -----

ln(Pd) = 5.01672 + -.777791 *ln(tau) + -.0481574 *[ln(tau)]^2

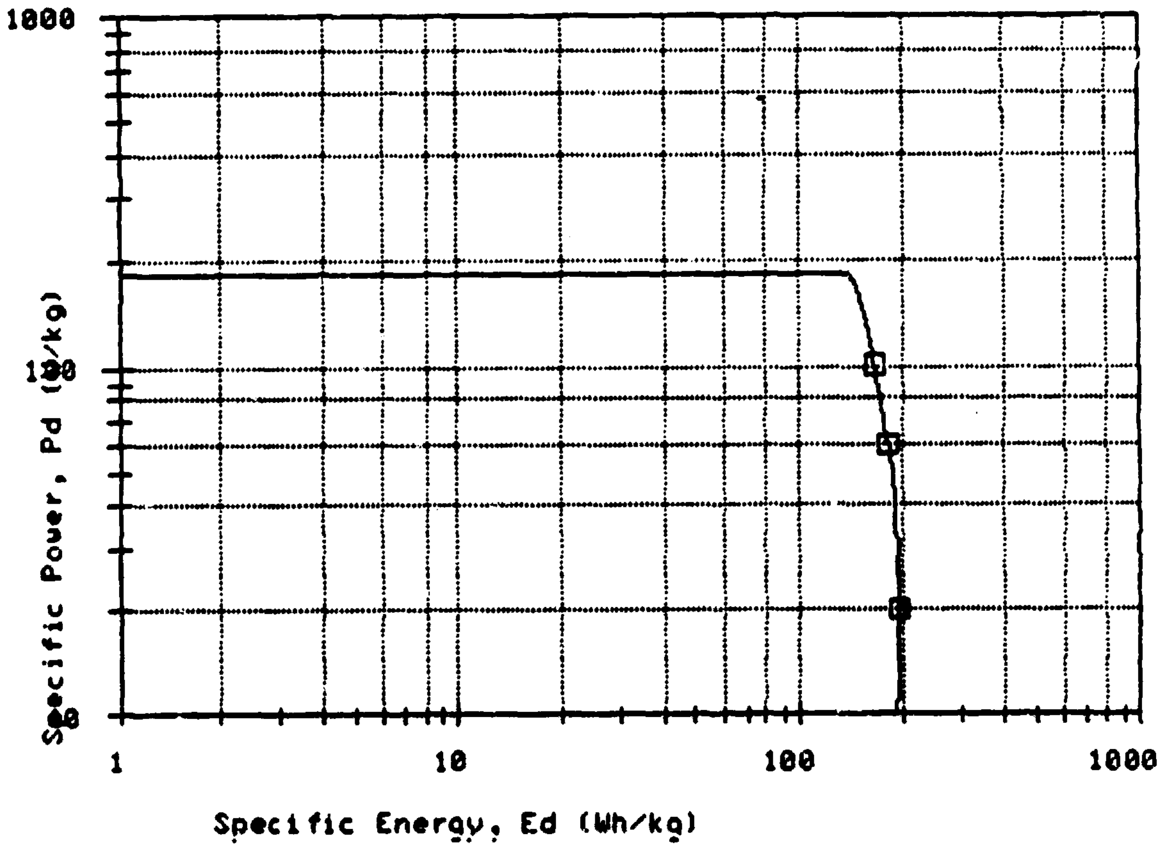
CH1 = 5.01672
CH2 = -.777791
CH3 = -.0481574

Sum of the squares of the residuals = 2.97917E-10
Standard error estimate = 1.72603E-05
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: FE/AIR 1.0

CH-1 = 5.01672   Pdmax = 181
CH-2 = -.777791
CH-3 = -.0481574



Battery model coefficient generator:

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FE/AIR 2.1

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20.134	134	6.65541	3.00241	1.89543
60	128	2.13333	4.09435	.757686
100	122	1.22	4.60517	.198851

RESULTS -----

ln(Pd) = 4.78288 + -.888354 *ln(tau) + -.0269051 *[ln(tau)]^2

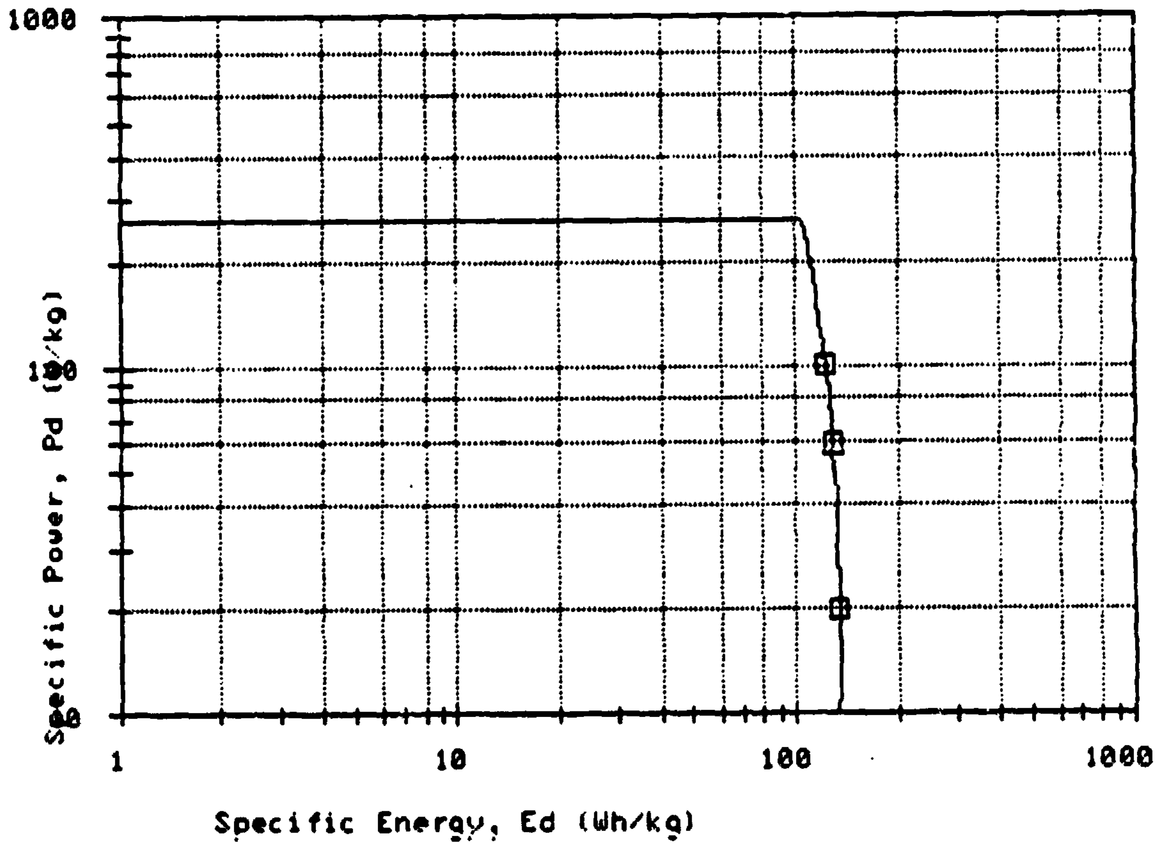
CH1 = 4.78288
CH2 = -.888354
CH3 = -.0269051

Sum of the squares of the residuals = 2.84217E-13
Standard error estimate = 5.3312E-07
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: FE/AIR 2.1

CH-1 = 4.78288 Pdmax = 262
CH-2 = -.888354
CH-3 = -.0269051



Battery model coefficient generator:

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FE/AIR 2.4

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	123	6.15	2.99573	1.81645
60	118	1.96667	4.09435	.67634
100	113	1.13	4.60517	.122217

RESULTS -----

ln(Pd) = 4.7158 + -.902187 *ln(tau) + -.0246366 *[ln(tau)]^2

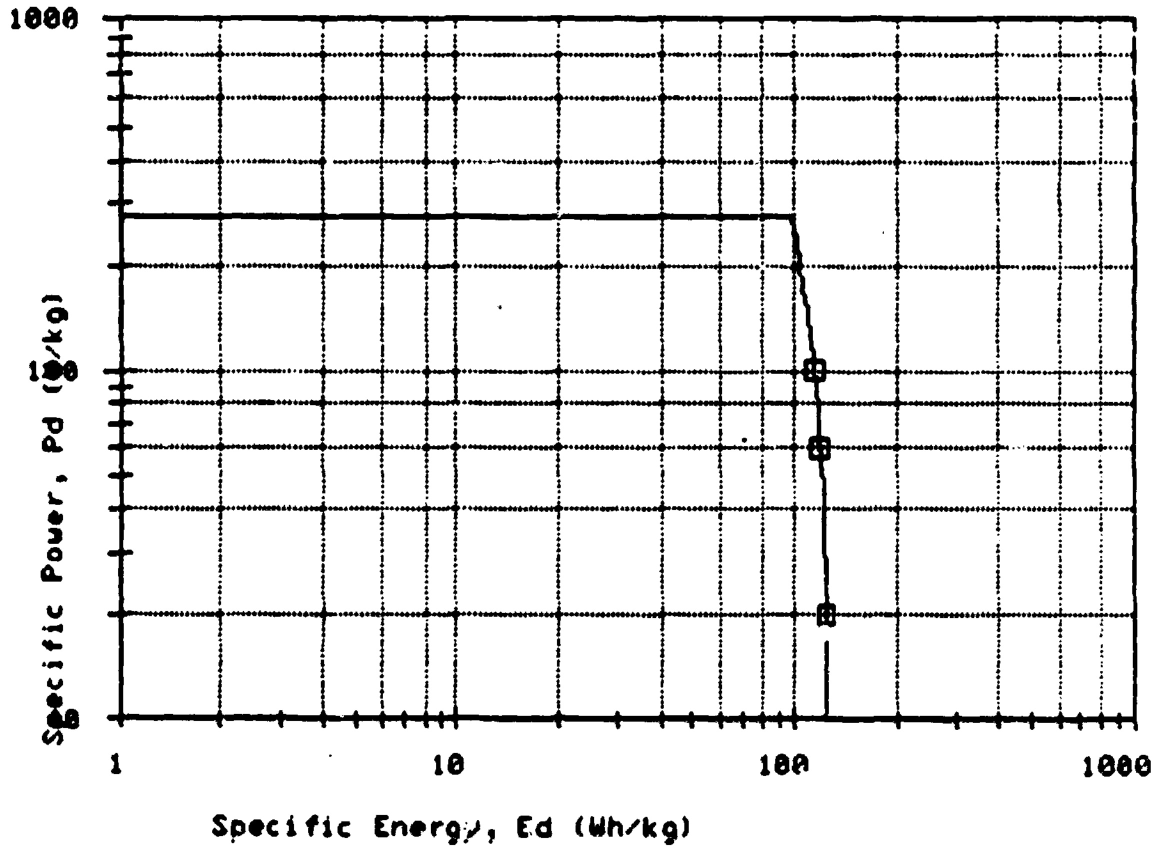
CH1 = 4.7158
CH2 = -.902187
CH3 = -.0246366

Sum of the squares of the residuals = 1.19371E-12
Standard error estimate = 1.09257E-06
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: FE/AIR 2.4

CH-1 = 4.7158   Pdmax = 277
CH-2 = -.902187
CH-3 = -.0246366



Battery model coefficient generator:

FE/AIR 3.3

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	98	4.9	2.99573	1.58924
60	94	1.56667	4.09435	.44895
100	91	.91	4.60517	-.0943106

RESULTS -----

ln(Pd) = 4.51707 + -.935427 *ln(tau) + -.0137498 *[ln(tau)]^2

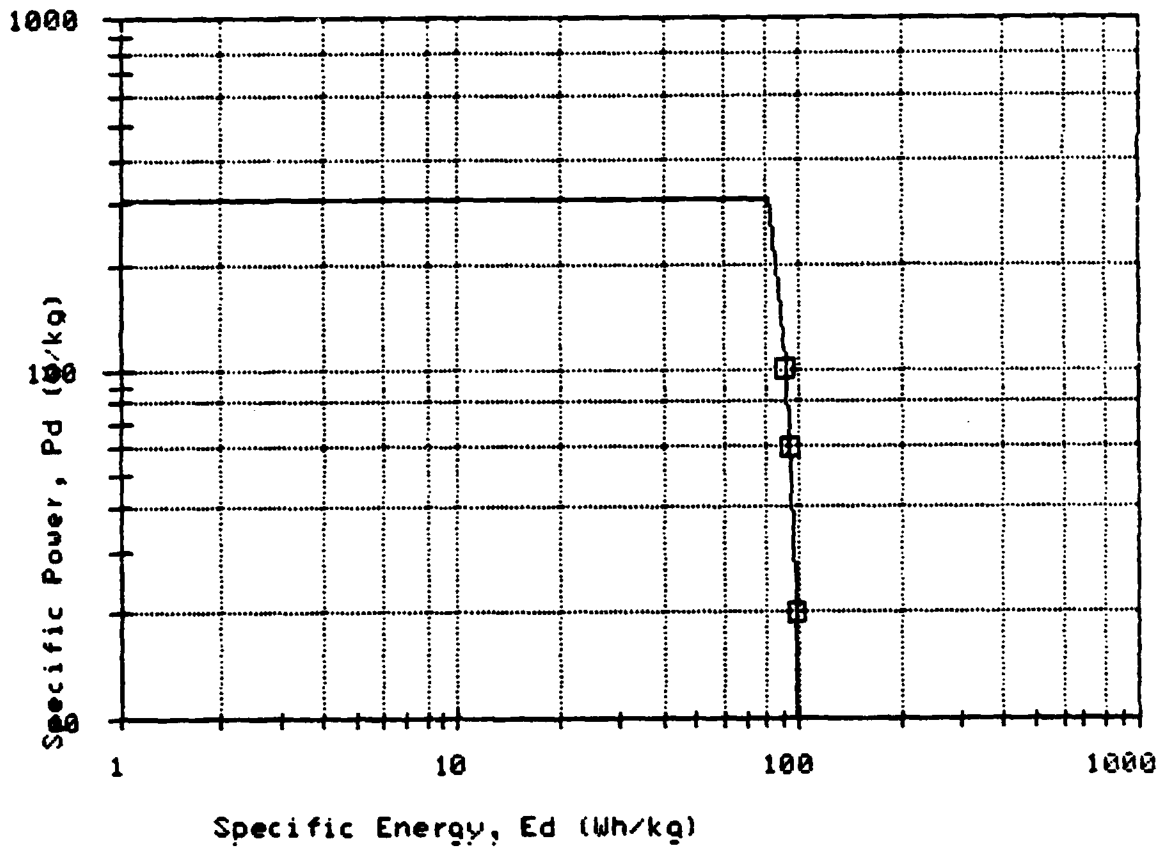
CH1 = 4.51707
CH2 = -.935427
CH3 = -.0137498

Sum of the squares of the residuals = 1.18803E-11
Standard error estimate = 3.44678E-06
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: FE/AIR 3.3

CH-1 = 4.51707 Pdmax = 309
CH-2 = -.935427
CH-3 = -.0137498



Battery model coefficient generator:

LI/FES 1.0 AND 3.3 - BIPOLAR

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	136	6.8	2.99573	1.91692
60	115	1.91667	4.09435	.650588
100	90	.9	4.60517	-.10536

RESULTS -----

ln(Pd) = 4.54047 + -.624021 *ln(tau) + -.0948519 *[ln(tau)]^2

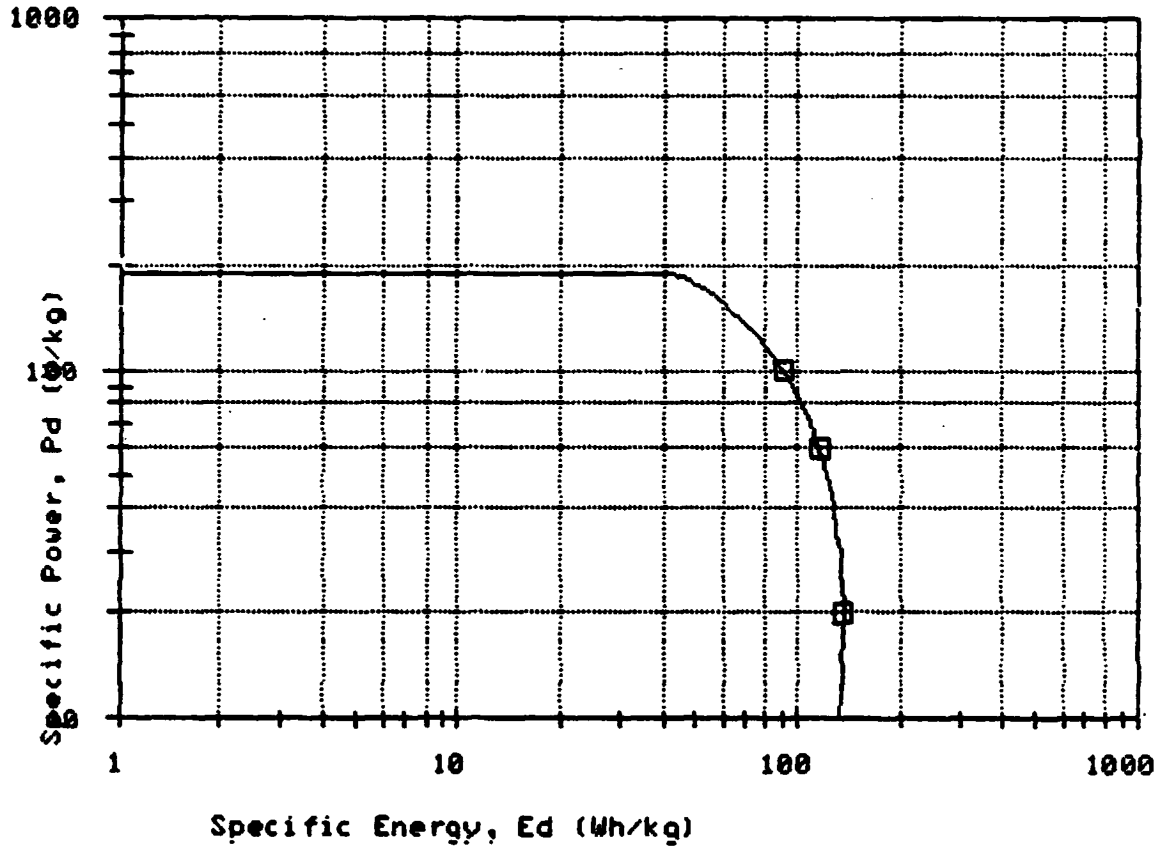
CH1 = 4.54047
CH2 = -.624021
CH3 = -.0948519

Sum of the squares of the residuals = 7.95808E-12
Standard error estimate = 2.82101E-06
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: LI/FES 1.0 AND 3.3 - BIPOLAR

CH-1 = 4.54047   Pdmax = 187
CH-2 = -.624021
CH-3 = -.0948519



Battery model coefficient generator:

LI/FES 2.1 AND 2.4 - PRISMATIC

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	87	4.35	2.99573	1.47018
60	75	1.25	4.09435	.223144
100	60	.6	4.60517	-.510826

RESULTS -----

ln(Pd) = 4.26029 + -.722844 *ln(tau) + -.093389 *[ln(tau)]^2

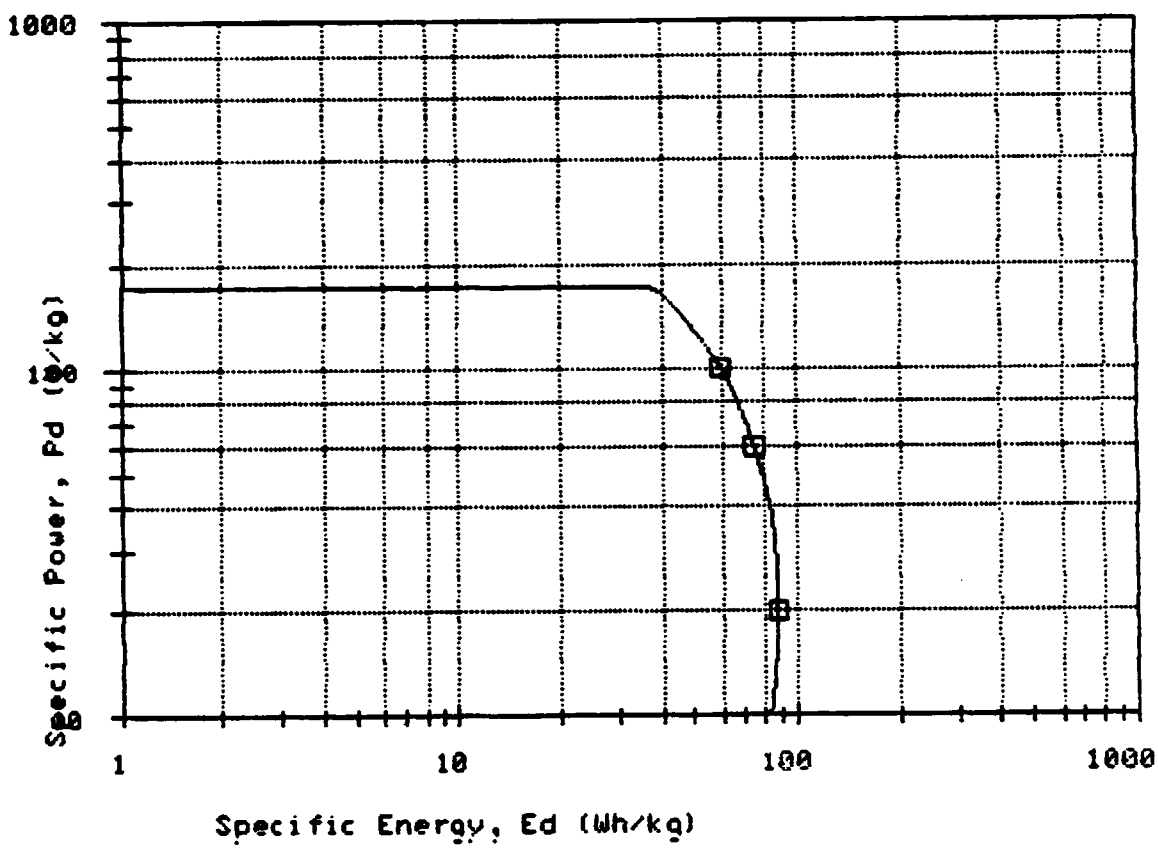
CH1 = 4.26029
CH2 = -.722844
CH3 = -.093389

Sum of the squares of the residuals = 2.27374E-13
Standard error estimate = 4.76837E-07
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: LI/FES 2.1 AND 2.4 - PRISMATIC

CH-1 = 4.26029 Pdmax = 170
CH-2 = -.722844
CH-3 = -.093389



Battery model coefficient generator.

NA/S 1.0

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	132	6.6	2.99573	1.88707
60	121	2.01667	4.09435	.701446
100	107	1.07	4.60517	.0676587

RESULTS -----

ln(Pd) = 4.65656 + -.755 *ln(tau) + -.0662971 *[ln(tau)]^2

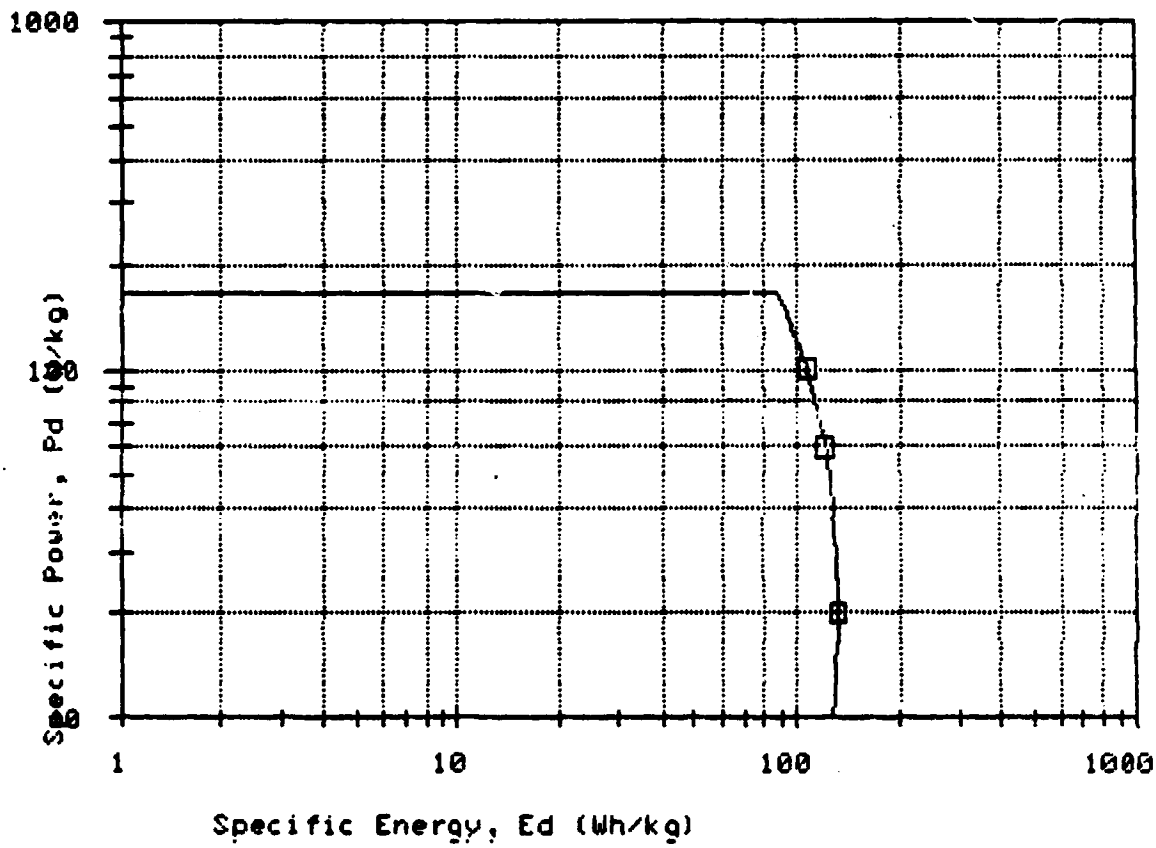
CH1 = 4.65656
CH2 = -.755
CH3 = -.0662971

Sum of the squares of the residuals = 0
Standard error estimate = 0
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: NA/S 1.0

CH-1 = 4.65656 Pdmax = 165
CH-2 = -.755
CH-3 = -.0662971



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Battery model coefficient generator:

NA/S 2.1

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	92	4.6	2.99573	1.52606
60	86	1.43333	4.09435	.360003
100	80	.8	4.60517	-.223143

RESULTS -----

ln(Pd) = 4.41274 + -.870809 *ln(tau) + -.0378316 *[ln(tau)]^2

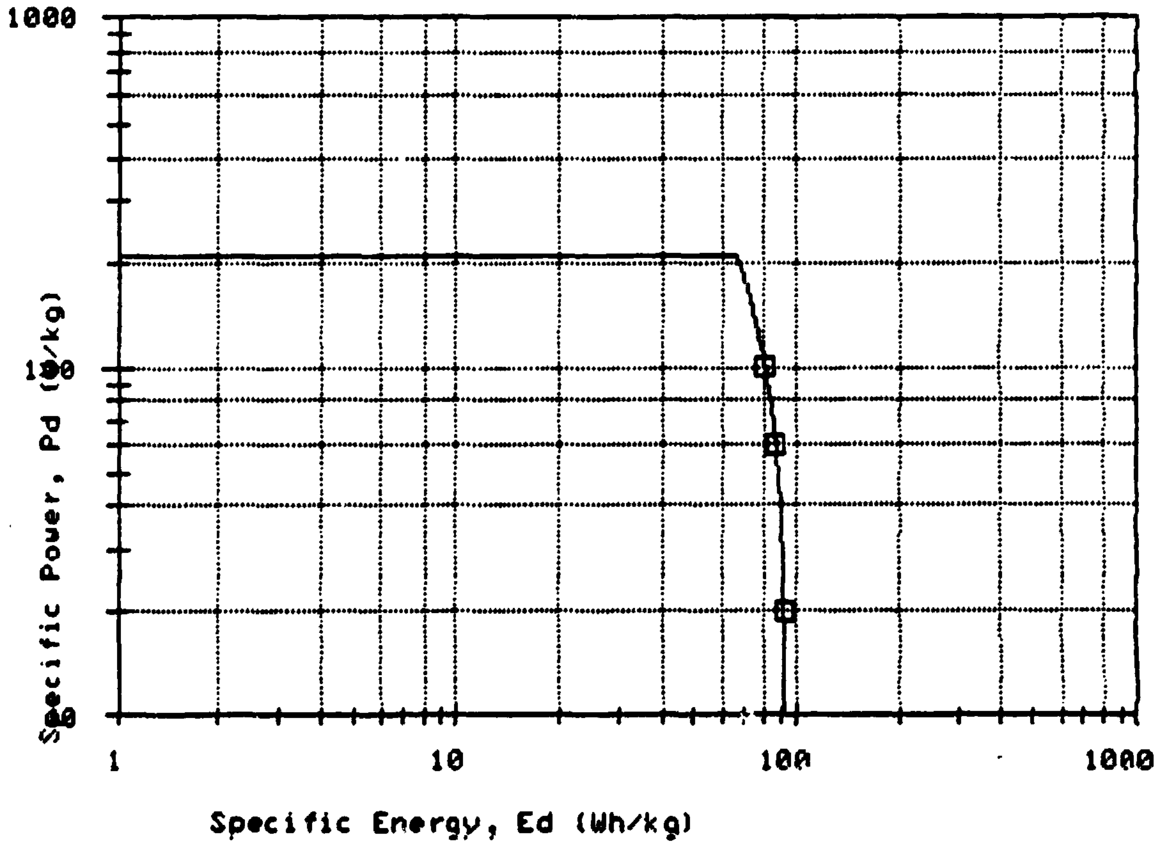
CH1 = 4.41274
CH2 = -.870809
CH3 = -.0378316

Sum of the squares of the residuals = 1.87583E-12
Standard error estimate = 1.36961E-06
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: NA/S 2.1

CH-1 = 4.41274   Pdmax = 209
CH-2 = -.870809
CH-3 = -.0378316



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Battery model coefficient generator:

NA/S 2.4

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	83	4.15	2.99573	1.42311
60	79	1.31667	4.09435	.275103
100	74	.74	4.60517	-.301105

RESULTS -----

ln(Pd) = 4.34162 + -.887594 *ln(tau) + -.040855 *[ln(tau)]^2

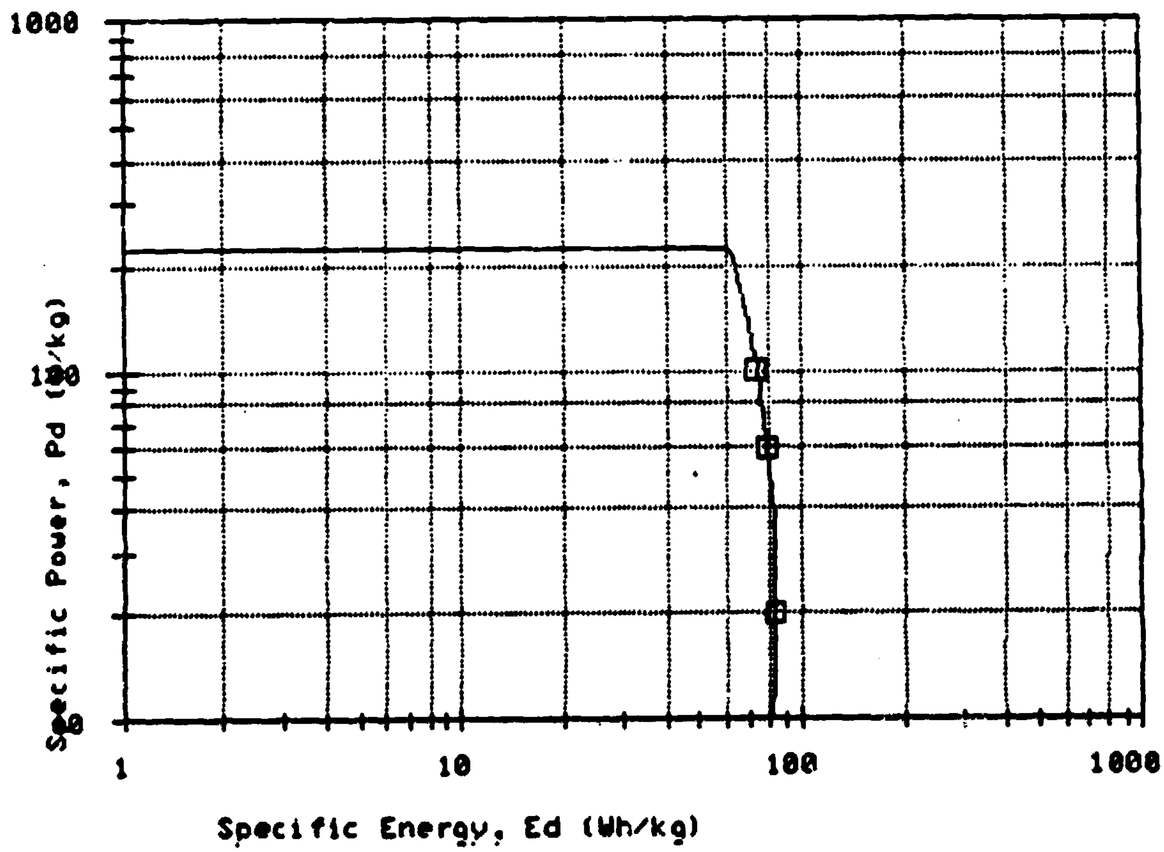
CH1 = 4.34162
CH2 = -.887594
CH3 = -.040855

Sum of the squares of the residuals = 6.82121E-13
Standard error estimate = 8.25906E-07
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: NA/S 2.4

CH-1 = 4.34162 Pdmax = 224
CH-2 = -.887594
CH-3 = -.040855



Battery model coefficient generator:

NA/S 3.3

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	73	3.65	2.99573	1.29473
60	69	1.15	4.09435	.139762
100	65	.65	4.60517	-.430783

RESULTS -----

ln(Pd) = 4.22143 + -.904752 *ln(tau) + -.0323847 *[ln(tau)]^2

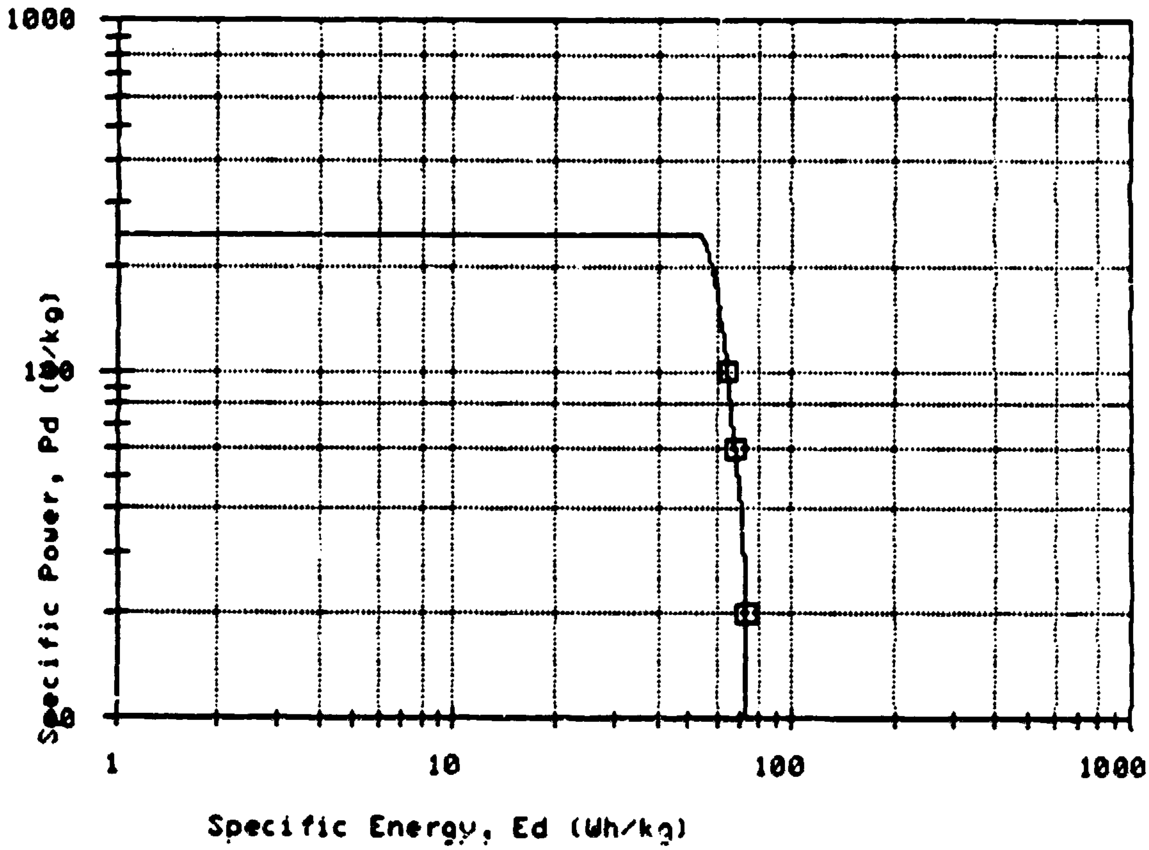
CH1 = 4.22143
CH2 = -.904752
CH3 = -.0323847

Sum of the squares of the residuals = 4.54747E-13
Standard error estimate = 6.74349E-07
Coefficient of determination = 1

ELVEC battery CH coefficient curve plot.....

For battery: NA/S 3.3

CH-1 = 4.22143 Pdmax = 244
CH-2 = -.904752
CH-3 = -.0323847



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Battery model coefficient generator:

AL/AIR

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	218	10.9	2.99573	2.38876
60	204	3.4	4.09435	1.22378
100	192	1.92	4.60517	.652325
200	164	.82	5.29832	-.198451

RESULTS -----

ln(Pd) = 5.14165 + -.803725 *ln(tau) + -.0397415 *[ln(tau)]^2

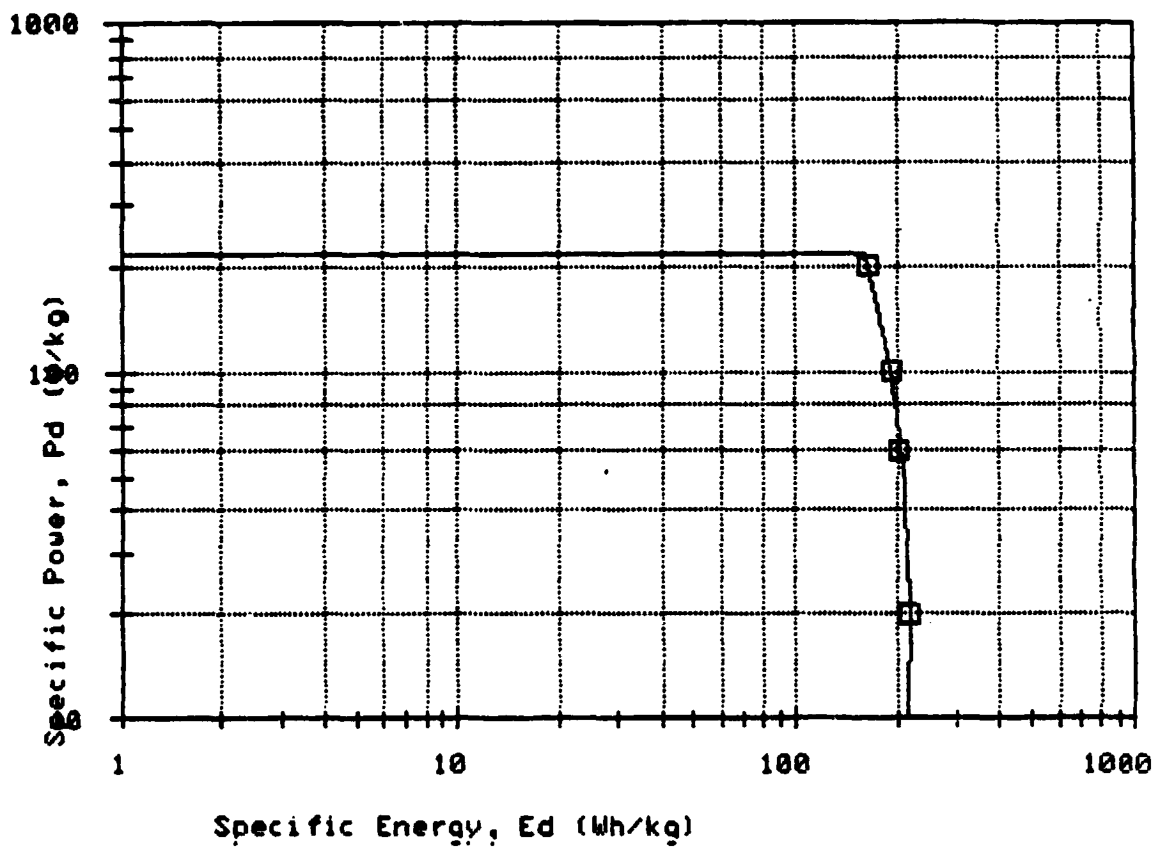
CH1 = 5.14165
CH2 = -.803725
CH3 = -.0397415

Sum of the squares of the residuals = 4.21929E-05
Standard error estimate = 4.59309E-03
Coefficient of determination = .999985

ELVEC battery CH coefficient curve plot.....

For battery: AL/AIR

CH-1 = 5.14165 Pdmax = 218
CH-2 = -.803725
CH-3 = -.0397415



Battery model coefficient generator:

AL/AIR/PRES

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	147	7.35	2.99573	1.9947
60	158	2.63333	4.09435	.968251
80	158	1.975	4.38203	.680569
100	151	1.51	4.60517	.41211
157	126	.802548	5.05625	-.219964

RESULTS -----

ln(Pd) = 4.91109 + -.703742 *ln(tau) + -.129094 *[ln(tau)]^2

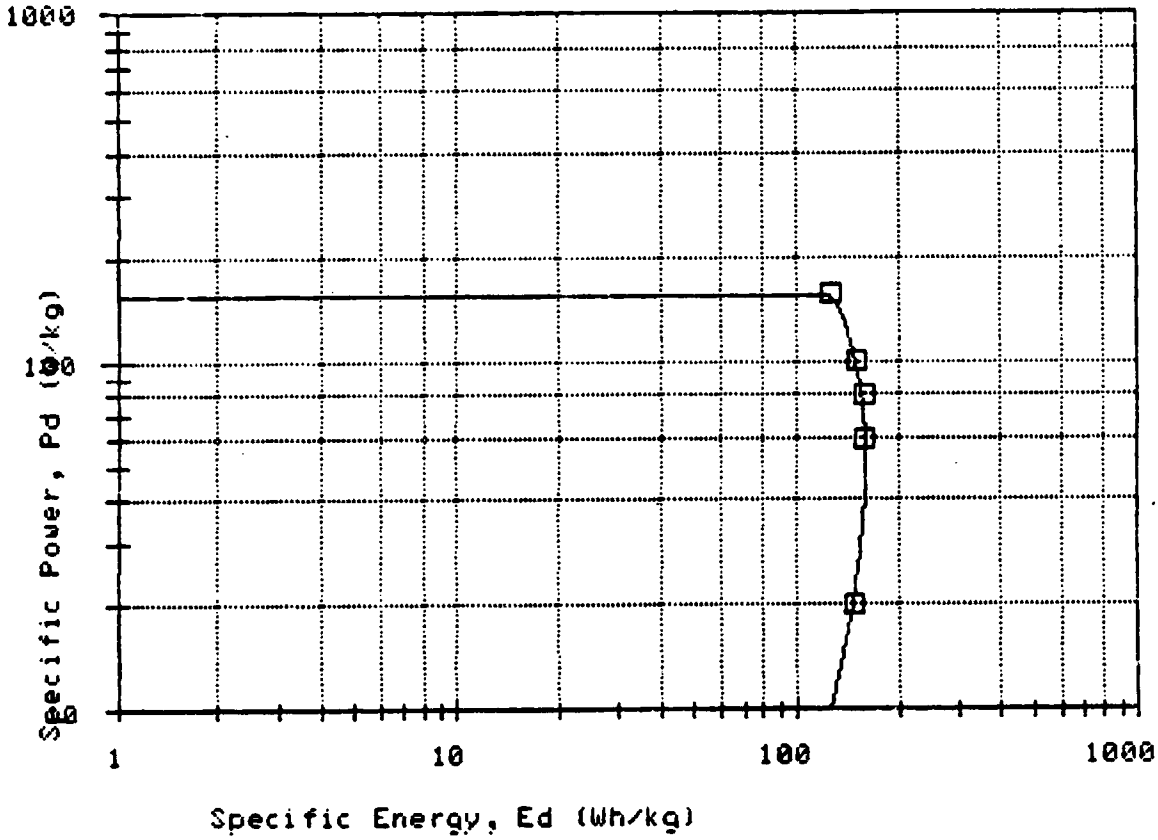
CH1 = 4.91109
CH2 = -.703742
CH3 = -.129094

Sum of the squares of the residuals = 3.50653E-04
Standard error estimate = .0108113
Coefficient of determination = .999853

ELVEC battery CH coefficient curve plot.....

For battery: AL/AIR/PRES

CH-1 = 4.91109 Pdmax = 157
CH-2 = -.703742
CH-3 = -.129094



Battery model coefficient generator:

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OF POOR QUALITY

AL/AIR/ADV

DATA -----

Pd	Ed	tau	ln(Pd)	ln(tau)
20	218	10.9	2.99573	2.38876
60	204	3.4	4.09435	1.22378
80	196	2.45	4.38203	.896088
100	192	1.92	4.60517	.652325
200	164	.82	5.29832	-.198451
218	145	.665138	5.3845	-.407761

RESULTS -----

ln(Pd) = 5.11411 + -.758579 *ln(tau) + -.0543494 *[ln(tau)]^2

CH1 = 5.11411
CH2 = -.758579
CH3 = -.0543494

Sum of the squares of the residuals = 2.44835E-03
Standard error estimate = .0247404
Coefficient of determination = .999366

ELVEC battery CH coefficient curve plot.....

For battery: AL/AIR/ADV

CH-1 = 5.11411 Pdmax = 218
CH-2 = -.758579
CH-3 = -.0543494